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Comparison of Leachate Characteristics from Selected Municipal Solid Waste Test Cells

Regional Services Corp., Inc., Columbus, IN

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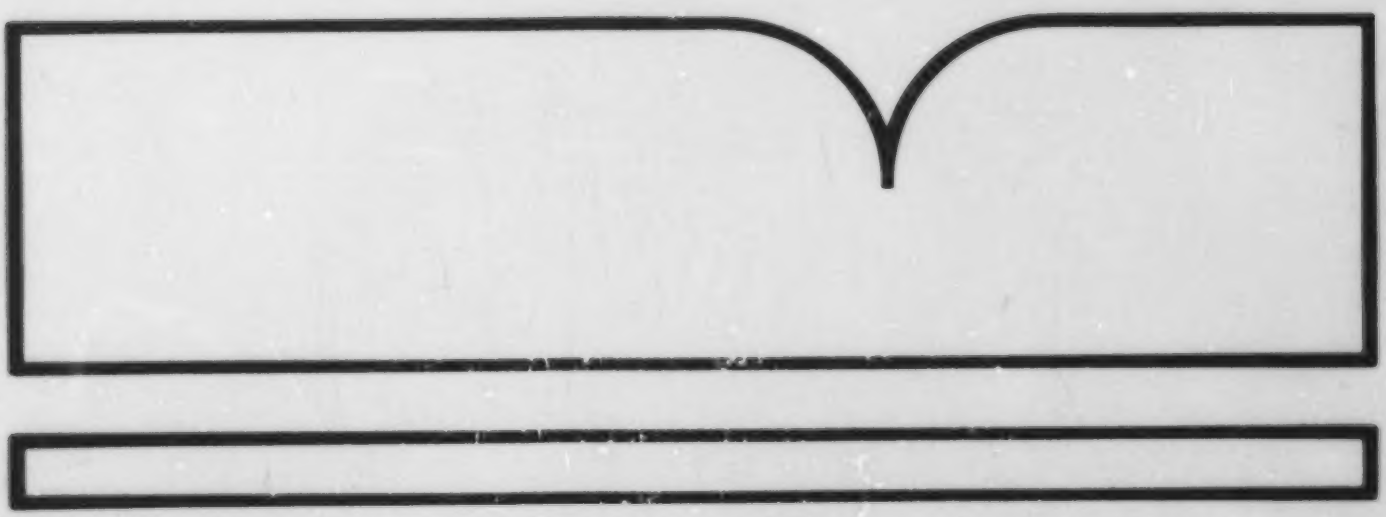

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COMPARISON OF LEACHATE CHARACTERISTICS FROM SELECTED MUNICIPAL SOLID WASTE TEST CELLS

by

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Order No. C2652NAST

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16. ABSTRACT

Sanitary landfills presently provide an economical method for solid waste disposal. Numerous research projects sponsored by U.S. EPA have involved monitoring refuse test cells to provide a better understanding of the processes that occur within the refuse mass and the potential environmental effects of sanitary landfills. The research effort described in this report was undertaken to determine if leachate characteristics from several different test cells were similar.

Normalized weighted mean leachate concentration histories and mass removals were compared graphically for two field-scale cells and three small-scale cells. A simple semi-empirical exponential model of leachate concentrations adequately described concentration trends. Identical performance of the test cells was not indicated from the data analysis, but rather a range of performance.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research - a most vital communications link between the researcher and the user community.

The information presented here documents the comparison of leachate characteristic data from the Boone County Field Site test cells to that from three (3) other similarly conducted experiments. The objective of the study was to determine whether the leachate composition and history of the other test cells was similar to that from the Boone County research effort.

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Director
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ABSTRACT

Sanitary landfills presently provide an economical method for solid waste disposal. Numerous research projects sponsored by U.S. EPA have involved monitoring refuse test cells to provide a better understanding of the processes that occur within the refuse mass and the potential environmental effects of sanitary landfills. The research effort described in this report was undertaken to determine if leachate characteristics from several different test cells were similar.

Normalized weighted mean leachate concentration histories and mass removals were compared graphically for two field-scale cells and three small-scale cells. A simple semi-empirical exponential model of leachate concentrations adequately described concentration trends. Identical performance of the test cells was not indicated from the data analysis, but rather a range of performance.

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SECTION I

INTRODUCTION

The Boone County Field Site (BCFS) was established to investigate production of leachate from municipal solid waste test cells and other environmental effects. Research was also directed at determining the effect of cell size on leachate characteristics and history, as well as performance comparison of identical small-scale cells. Five municipal solid waste test cells were constructed during 1971 and 1972. The research was concluded and the site closed in September 1980. The final report was published in 1983 (1).

One of the primary conclusions reached in the BCFS study was that most of the leachate constituent concentration histories showed generally similar trends. The concentration history appeared to be based more on cumulative leachate volume rather than time. Results also indicated that both identical cells and different sized cells demonstrated a range of leachate behavior rather than statistical similarity. The objective of this study was to compare other municipal refuse test cell research results with that of BCFS to determine whether leachate characteristics might be similar over a wider range of experimental conditions.

SECTION II

SUMMARY AND CONCLUSIONS

Leachate concentrations and mass removals for several chemical parameters were compared for five sanitary landfill test cells from four U.S. EPA studies. Two of the cells were field-scale. One was used in research at the Boone County Field Site and the other in Sonoma County, California. The other three cells were small-scale, containing from 636-2113 kg of dry refuse. Research with these small cells was conducted at the Boone County Field Site, the Center Hill research facility in Cincinnati, and by Pohland at Georgia Tech.

Refuse depths and densities for the two field-scale cells were almost identical. Leachate production rates in the Sonoma study were almost three times that of the Boone County cell. Field capacity of the refuse was estimated to be 1.22 l/kg of dry refuse at BCFS and 1.20 l/kg in the Sonoma County cell. Refuse depths and densities for the three small cells varied from 2.4 - 2.9m and 210 - 314 kg/m^3. Average annual leachate production over the period from initial leachate collection to completion of the study ranged from .57 l/kg of dry refuse/year at Boone County, to .99 l/kg/year at Center Hill, to an estimated 2.15 l/kg/year in the control cell at Georgia Tech. Leachate production in the Pohland study was not measured, but estimated from moisture input. This precluded accurate comparison of the performance of the cell with the other two.

Only 3 of 17 commonly measured leachate constituents were analyzed on a regular basis for all of the five test cells. This lack of a standard operating procedure prevented comparison of leachate composition and history over a broad range of leachate parameters. Only COD, chloride and iron were common to all of the studies.

Graphical comparison of weighted mean concentration histories and mass removals for the two field scale cells indicated performance similarity for COD, sodium, potassium and ammonia-N. Chloride concentrations and mass removals had similar trends, but the Sonoma data was very erractic during the late portions of the study. Iron concentrations showed little similarity. Indications were that iron concentrations were diluted by higher rates of leachate flow, apparently due to a time dependent rate of iron availability from the refuse mass. Calcium removals in the Sonoma study were only 60% of that removed in the Boone County field cell, perhaps due to dilution from higher leachate production. Ammonia-N removal differed by only 15% at a cumulative leachate volume of 4.5 l/kg of dry refuse.

Graphical comparison of leachate characteristics from the small-scale cells was limited to the Boone County and Center Hill studies due to the lack of leachate volume data from the work by Pohland. Weighted mean concentrations of COD for Boone County and Center Hill had similar peaks at field capacity followed by comparable downward trends. Mass removals were almost identical over the full range of the study. COD mass removed from the field-scale cells was only 60% of that from the two small ones. Peak concentrations of chloride in the two small cells were only slightly different, but the concentrations in the Boone County cell tended to be higher throughout the study period, resulting in a mass removal almost twice that recorded at Center Hill. Iron showed very little similarity in concentration or mass removal, perhaps due to limited solubility and subsequent dilution in the higher flow Center Hill cell.

Prediction of test cell leachate characteristics with a semi-empirical model indicated that the simple exponential equation adequately described concentration trends as measured by the correlation coefficient for over half of the parameters. Generally lower peak concentrations were predicted for cells with the highest leachate production rates. The mass generation rate constant was found to increase with higher leachate flow rates. Comparisons based on total estimated leachable mass indicated performance similarity for three of the seven parameters used to compare the field scale cells.

While exact similarity of cell performance was not apparent for the leachate parameters for the five test cells, the data does indicate concentrations and mass removals to fall within a range. Noticeable trends for all cells were peak concentrations for many parameters at field capacity, and lower peak concentrations with higher leachate flow rates. Concentration magnitudes and mass removals tended to be more a function of cumulative leachate volume than time. While many of the leachate concentration trends could be adequately described by a simple exponential equation, further modifications to the theory would be beneficial for future comparison of cells based on model predictions.

SECTION III

RECOMMENDATIONS

Comparison of long term municipal leachate concentration and mass removal trends indicates that while test cell performance is not identical, there are sufficient similar trends to enable ranges in behavior to be defined and perhaps predicted with a mathematical model. To further this work it is recommended that future research work include:

1. Analysis of leachate data from all test cell work that has been performed.

2. Comparison of test cell performance with data from actual sanitary landfills.

3. Development of a mathematical model that adequately describes the leaching process, particularly the internal transfer of constituent mass to the water moving through the refuse.

4. Determining the range of leachate flow rates over which concentrations and mass removals exhibit similar characteristics.

5. In future research efforts, a standard protocol for measuring leachate volumes and for chemical analysis of the leachate should be followed so that comparisons with other studies can be made over a broader range of parameters.

SECTION IV

SELECTION OF CASE STUDIES

LITERATURE REVIEW

The initial objective of this study was to compare the leachate composition and history from BCFS cell #1, with that of three (3) other field-scale municipal refuse experiments. This required the other cells to be somewhat similar to BCFS cell #1, particularly the refuse depth, and with an in-place refuse mass of at least 200 dry tonnes. In addition it was necessary that sufficient leachate had been produced and collected to enable comparisons over a cumulative leachate volume of at least 3.5 liters of leachate per kg of dry refuse. It was also desired that at least five of the same leachate analytical parameters had been measured during the study period.

Over 20 selected references were reviewed for possible use as comparative cells. The early work of Merz and Stone (2) was not applicable due to the lack of a liner in the base of the cell and the quantity of leachate collected. The field scale cell constructed by Fungaroli and Steiner (3) did not have a leachate collection system and therefore could not be used in this effort. The study of five operating landfills by SCS Engineers (4) was not applicable due to the length of the study period and several other factors. The work of Ham (5) with large lysimeters in Madison, Wisconsin met the cell characteristic requirements, but the leachate collected from cell #8 only amounted to .72 l/kg of dry refuse, far short of the 3.5 l/kg needed for meaningful leachate composition history compared with BCFS cell #1. The only field-scale cell reported in the literature which had a sufficient leachate history and was of similar construction to BCFS cell #1 was one of five cells monitored in Sonoma County, California from 1971-1976 (6). While this cell had a soil rather than a synthetic liner, the extensive leachate collection system and relatively impervious sandy clay subsoil liner probably prevented extensive loss of leachate. The Sonama County cell "C" was therefore selected as one of the comparative study cells.

Since data from three field-scale cells was not available for comparison to BCFS #1, two small-scale cell studies were selected to be compared to the smaller BCFS #2B, a cylindrical test cell containing 2113 kg of dry refuse at a maximum depth of 2.56m. One of these was the control cell utilized by Pohland (7) for comparison to several cells with leachate being recycled. The final comparative cell was #4 from SCS Engineers' work for the Solid and Hazardous Waste Research Division at the Center Hill facility in Cincinnati, Ohio (8).

Sonoma County

Under EPA sponsorship, five field-scale test cells were constructed in Sonoma County, California to study the effect on refuse stabilization of applying excess water, septic tank pumpings and recirculated leachate. These cells were monitored for over four years, from late 1971 until early 1976. The work was performed by the Sonoma County Department of Public Works and Emcon Associates. (6,9)

Test cell C, the control cell which was operated similarly to BCFS #1, was approximately 18 meters square and 3 meters in total depth. Approximately 2650 l/day of water were added to the cell through distribution lines beneath the final cover soil to supplement natural rainfall. The cell contained approximately 765 cubic meters of compacted refuse weighing 473.7 tonnes, wet weight. Cell design is depicted in Figure 1.

Leachate was collected from the base of the cell by a series of perforated pipes embedded in sand and gravel filled trenches excavated into the natural sandy clay soil. Leachate collected averaged 70% of water input. Losses were attributed to evaporation.

Pohland Studies

Four simulated landfill cells were constructed at the Georgia Institute of Technology during 1971 and 1972 to study the feasibility of leachate recycling. Construction details are depicted in Figure 2 from the project report. (7) These cells were monitored for approximately 3 years after leachate production began. One of these cells was used as a control, receiving no recycled leachate.

This control cell was constructed in epoxy coated 91 cm diameter corrugated steel pipe. Leachate was collected in a sealed drain line. Thirty-three days after construction of the cell 946 liters of tap water were added to the surface of the fill to hasten the achievement of field capacity and leachate production. Refuse placed in the fill was coarsely ground with a brush chipper. A total of 635.6 kg of dry refuse was placed in the cell and compacted to a dry density of 185.7 kg/cubic meter. An additional 178.8 cm of precipitation fell on the sod cover of the fill during the life of the project.

Center Hill Studies

Nineteen sanitary landfill test cells containing municipal solid waste were constructed at the Center Hill Laboratory in Cincinnati, Ohio during 1974 and 1975. Each test cell contained approximately 3,000 kg (wet weight) of municipal refuse. Typical cell construction is shown in Figure 3 from the project report. The cells were located outdoors below the ground surface.

Four of the cells contained municipal refuse only. Moisture input to these four cells varied from 203-813 mm/year. To simulate actual landfill conditions, the cells received water in varying monthly amounts in accordance with average midwestern seasonal infiltration conditions. For this

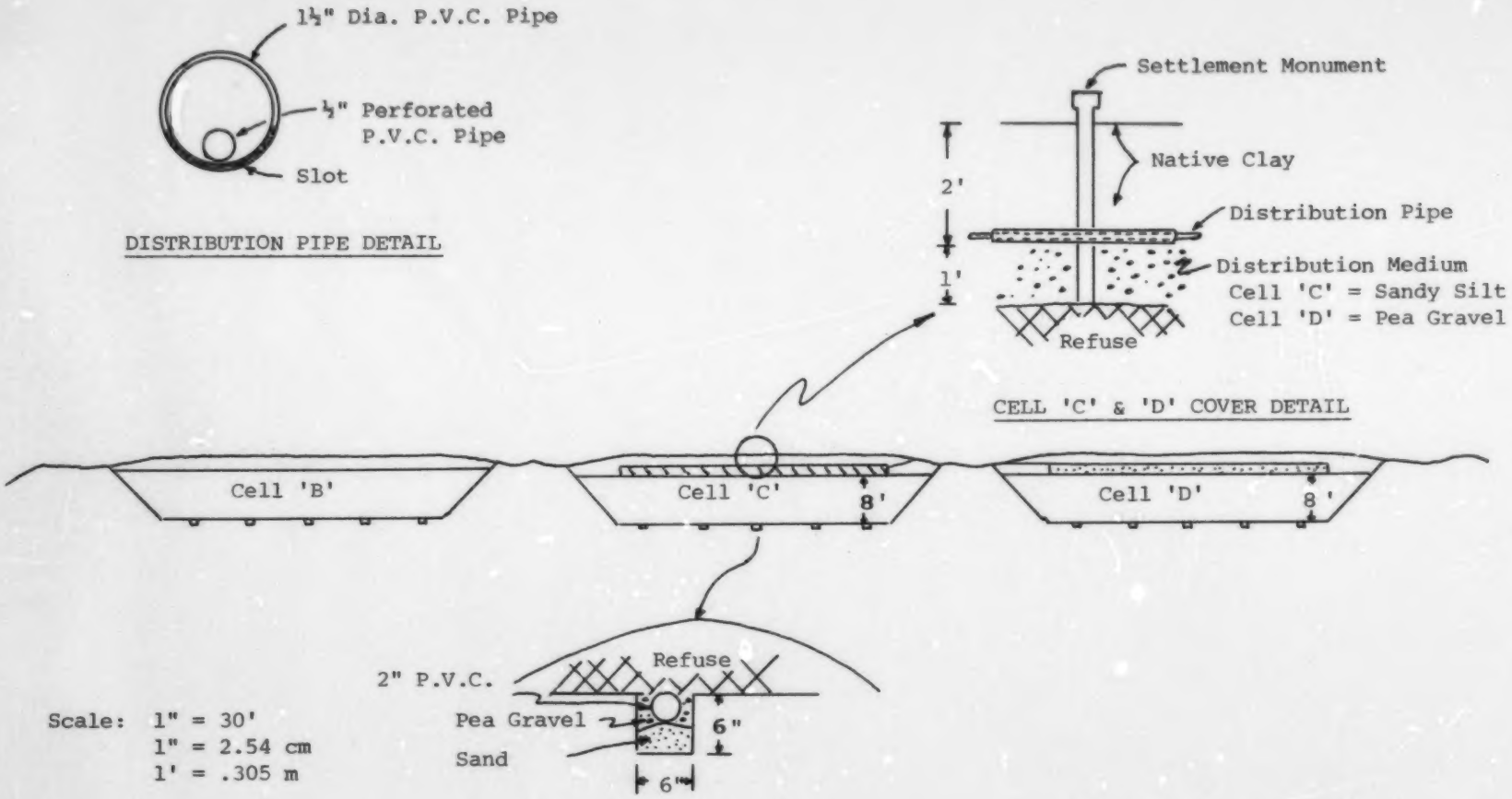

Figure 1. Sonoma County Cell C

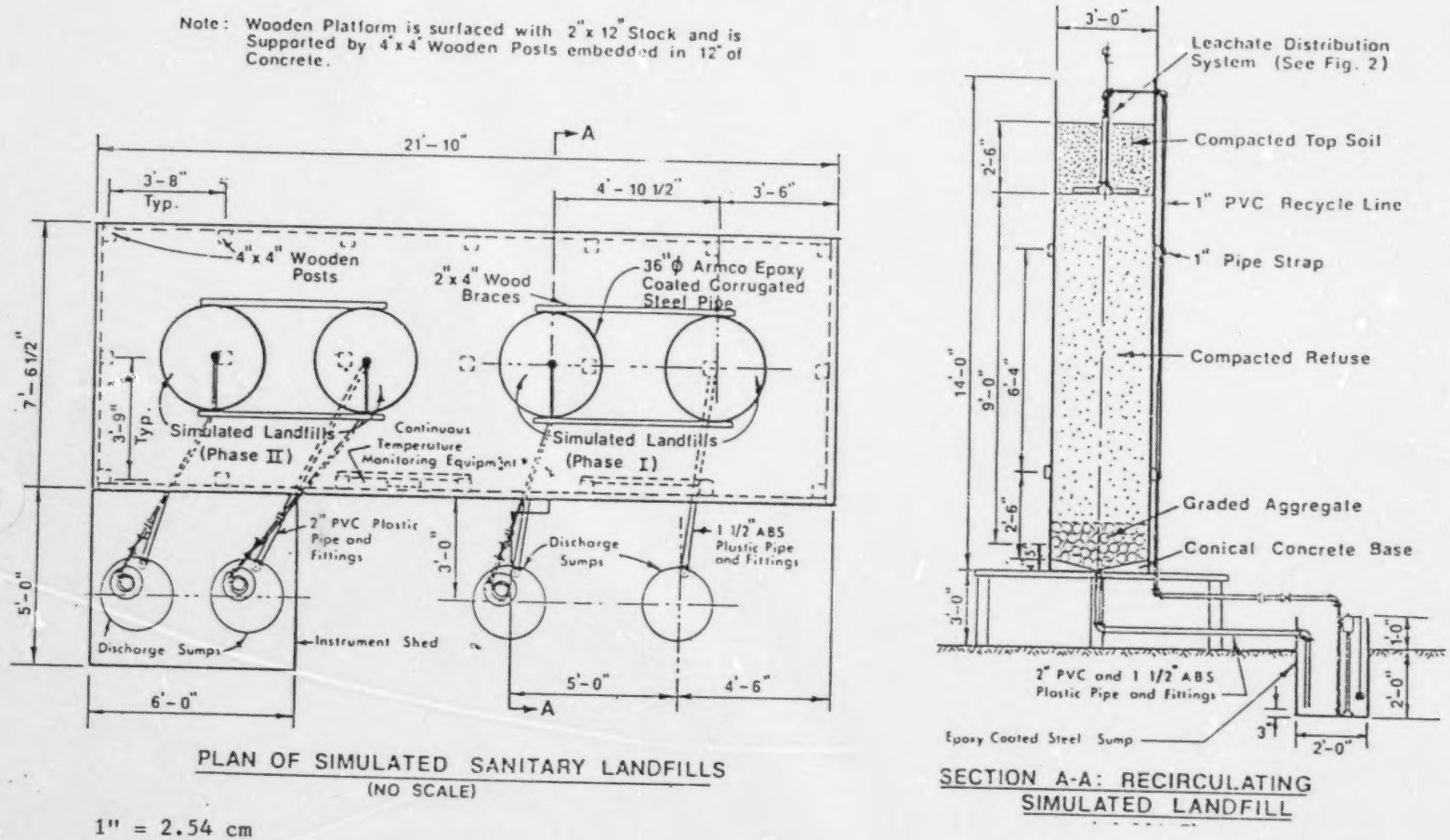

Figure 2. Pohland/Georgia Tech Cell

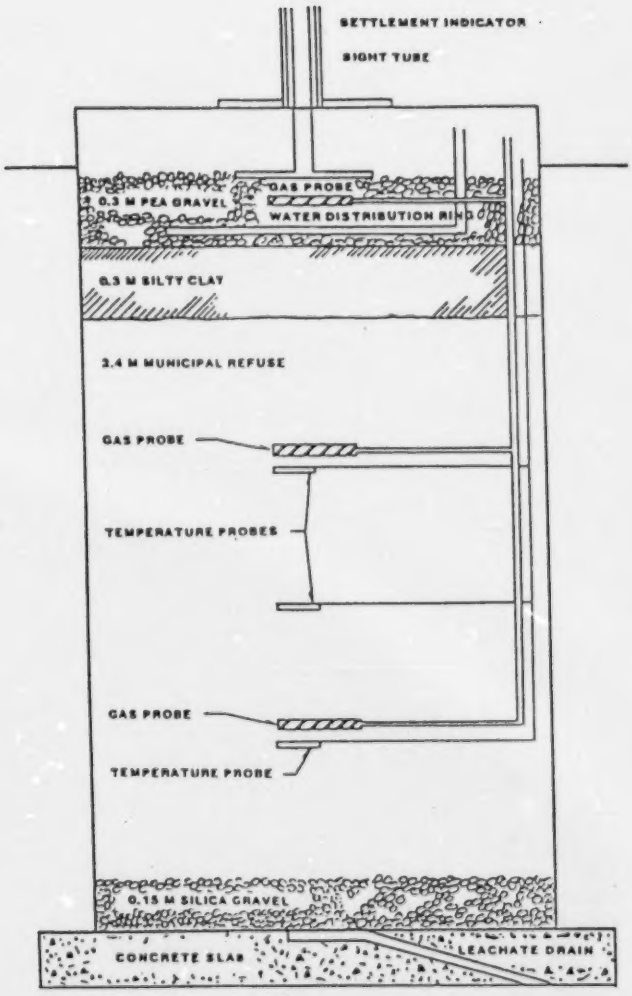

Figure 3. Cell #4, Center Hill Studies

study, cell #4, receiving 813 mm/year of water, was selected for comparison to the control cell of Pohland and the BCFS #2B. The #4 cylinder contained 1855.2 kg of dry refuse at a density of 289.9 kg/m^3. A total of 2136 liters/year of water was added to the cell. Leachate analyses were done monthly.

SECTION V

LEACHATE COMPOSITION COMPARISONS

CELL DATA

Summarized data for the selected test cells is presented in Table 1. The two field-scale cells, BCFS #1 and Sonoma C, are relatively consistent in terms of depth and initial in-place dry density. The average annual leachate production per kilogram of dry refuse is over 3 times higher for the Sonoma County cell than the Boone County cell due to higher water input.

TABLE 1. SUMMARY OF TEST CELL DATA

Test Cell	Avg. Annual[a] Leachate	Refuse Mass[b] Dry Weight	Max. Refuse Depth[c]	Refuse Dry Density[d]
BCFS #1	.57	286,000	2.56	429
Sonoma Co. Cell C	1.91	352,000	2.62	460
BCFS #2B	.58	2,113	2.56	314
Pohland-Control	2.15*	636*	3.28	186
Center Hill #4	.99	1,855	2.4	290

a. l/kg of dry refuse/year
b. kg
c. meters
d. kg/m^3

*Estimated Values

Findings from Boone County and Center Hill indicated that leachate concentration history was more dependent on cumulative leachate volume than time. Therefore by normalizing the data over cumulative leachate volume, the leachate concentrations and mass removals could be compared.

Refuse densities and depths for BCFS #2B and Center Hill #4 were very similar. The depth for the Pohland control cell initially was 3.28m, however, within about one month settlement had reduced the fill height to 2.9m. This settlement would make the in-place dry density 210 kg/m^3, somewhat closer to BCFS #2B and Center Hill #4. Leachate production rates varied widely for the three small cells. The Table 1 values for initial dry weight of refuse and the average annual leachate flow for the Pohland study had to be estimated, as moisture content of the refuse at cell construction was not reported in the literature. Leachate volumes were also not reported and had to be calculated from concentration data and estimated masses of constituent extraction.

Comparison Parameters

It was desired to compare leachate composition and history for the five test cells for at least five analytical parameters. Table 2 presents the more common leachate chemical data that was reported on a regular basis for the entire life of the studies.

TABLE 2. REPORTED LEACHATE PARAMETERS

Parameter	BCFS #1	Sonoma Co. Cell C	BCFS #2B	Pohland Control	Center Hill #4
Total Solids	x	-	x	-	x
Dissolved Solids	-	x	-	-	-
Conductivity	x	x	x	-	x
Chloride	x	x	x	x	x
Sulfate	x	-	x	-	-
TKN	x	x	x	-	x
Ammonia-N	x	x	x	x	-
Nitrate	-	x	-	-	-
TOC	-	-	-	x	x
COD	x	x	x	x	x
BOD	-	x	-	x	-
Potassium	x	x	x	-	-
Sodium	x	x	x	x	-
Calcium	x	x	x	x	-
Magnesium	x	x	x	x	-
Iron	x	x	x	x	x
Hardness	x	-	x	x	-

For these five cells only COD, chloride and iron were analyzed on a regular basis throughout the entire project period for all five studies. As a result comparative analysis for all the cells could only be done for these parameters. Data for calcium and sodium was compared for all but the Center Hill cell. Potassium data from BCFS #1 and Sonoma C was also compared.

Graphical Comparison

Since leachate flow rates and sampling intervals for all the studies were different, it was necessary to calculate weighted mean concentrations of the leachate parameters at common points in the leachate flow history. This was done by calculating the mass of the parameter (concentration times water volume) that was removed from the refuse between sample analyses over the interval of leachate flow, usually .5 l/kg of dry refuse. This mass was then divided by the volume of leachate to give a weighted mean concentration for the leachate volume interval. Cumulative mass removals were obtained by adding the incremental masses used in calculating the weighted mean concentrations.

The concentration history and mass removal curves for the selected leachate quality parameters are presented in Figures 4-28. Weighted mean concentrations and cumulative mass removals have been plotted against cumulative leachate volume rather than time. Leachate volume and mass removal data are also normalized by dividing by the dry weight of the refuse to account for the different size of the cells.

Chemical Oxygen Demand--

The weighted mean concentration and cumulative mass removal for COD for the two field scale cells is shown in Figures 4 and 5. Concentration trends and peaks are quite similar considering the fact that the annual leachate production from the Sonoma County cell was 3.35 times higher than that from BCFS #1. While there were individual weighted mean concentration differences of almost 10,000 mg/l, the cumulative mass removal curves of Figure 5 are almost identical.

For the small scale cells, depicted in Figures 6 and 7, concentrations for BCFS #2B and Center Hill #4 have similar peaks and similar though erratic trends. The concentration data from the Pohland control cell is similar after a cumulative leachate volume of 2.5 l/kg of refuse to that from the other cells, but the early concentrations are much less. The common peak concentration at field capacity is totally absent. These depressed concentrations could be due to the fact that almost 1/3 of the water added to the cell was introduced in the initial 90 days of the 3 year study, possibly resulting in extreme short-circuiting of water through the refuse mass. Also, since leachate volumes were not recorded, the estimates that were made in the Pohland study of mass removals may not be accurate. The low concentrations during the early phases of the Pohland cell result in a mass removal curve significantly different from those for BCFS and Center Hill. COD removal from the two large scale cells was only 60% of that from the two similar small cells. In the Boone County study (1) this difference was attributed to possible diluting side wall leakage into the cells and the greater potential for water short-circuiting through the larger refuse mass.

Chloride--

Figures 8 and 9 depict the weighted mean chloride concentrations and mass removals for the two field scale cells. The trends are similar until a cumulative leachate volume of 3.5 l/kg of dry refuse was reached. At this point the chloride recorded at Sonoma County increased significantly. One individual sample had a value of over 10,000 mg/l. Large increases in conductivity or dissolved solids were not recorded in the sample, indicating that perhaps the chloride value reported resulted from laboratory error. In a one year extension of the Sonoma County study (9), chloride levels dropped into the 60-850 mg/l range, very erratic but much closer to the levels recorded at BCFS #1. Mass removal at 4 l/kg of dry refuse, as shown in Figure 9, was identical for both cells. The later questionable concentrations at Sonoma tended to increase the mass removal rate for that cell.

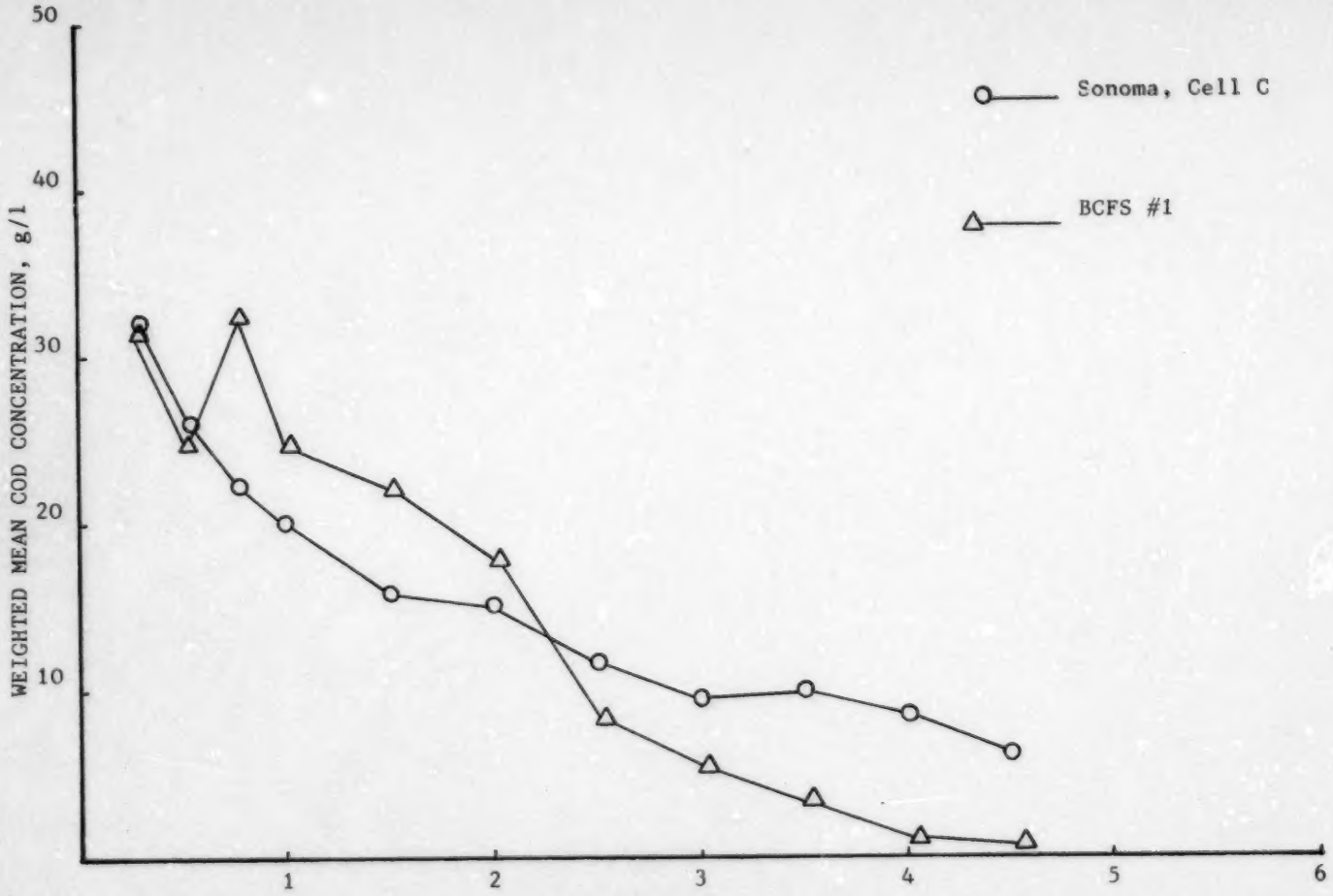

Figure 4. COD concentration history

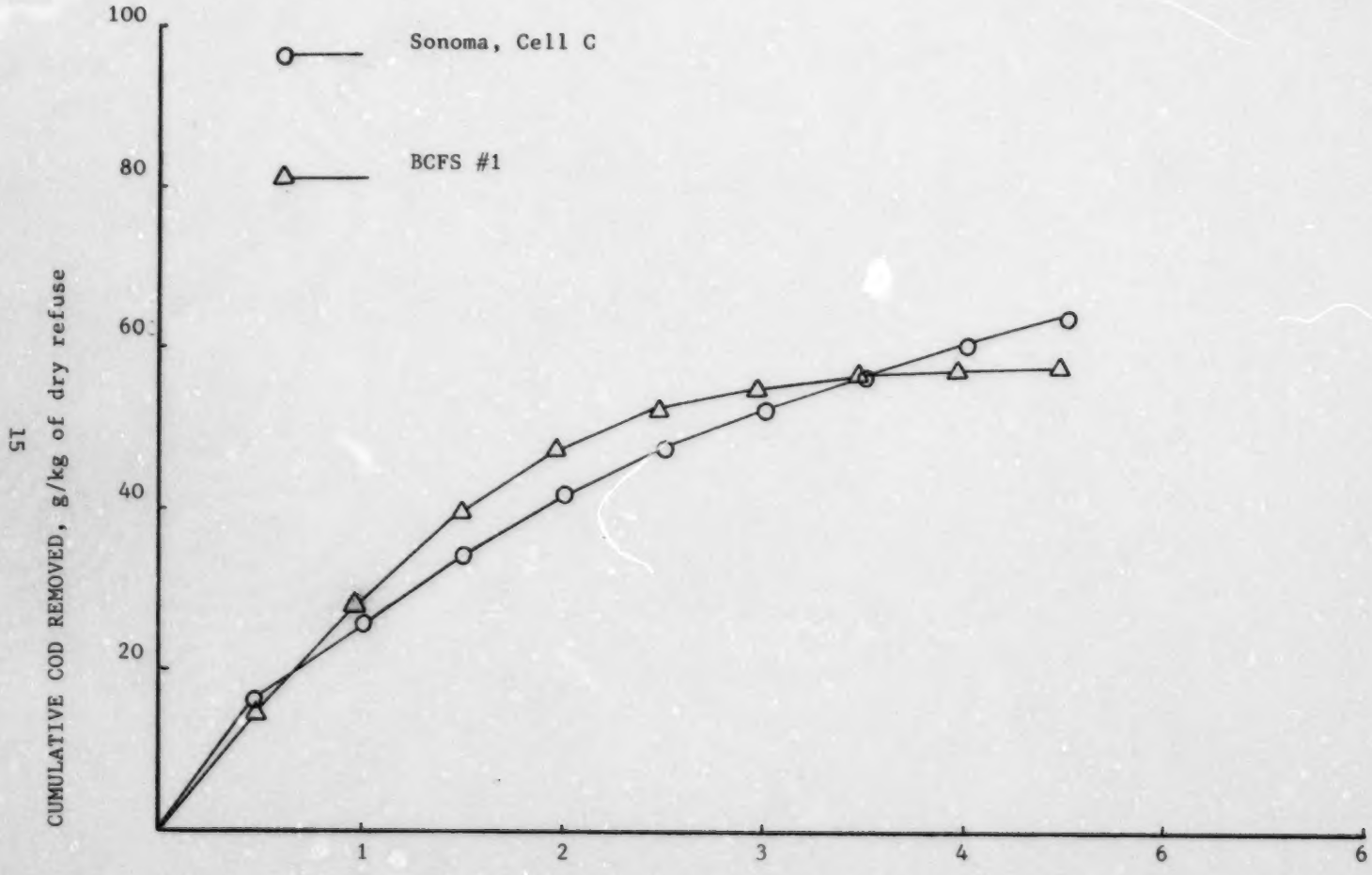

FIGURE 5. COD mass removal.

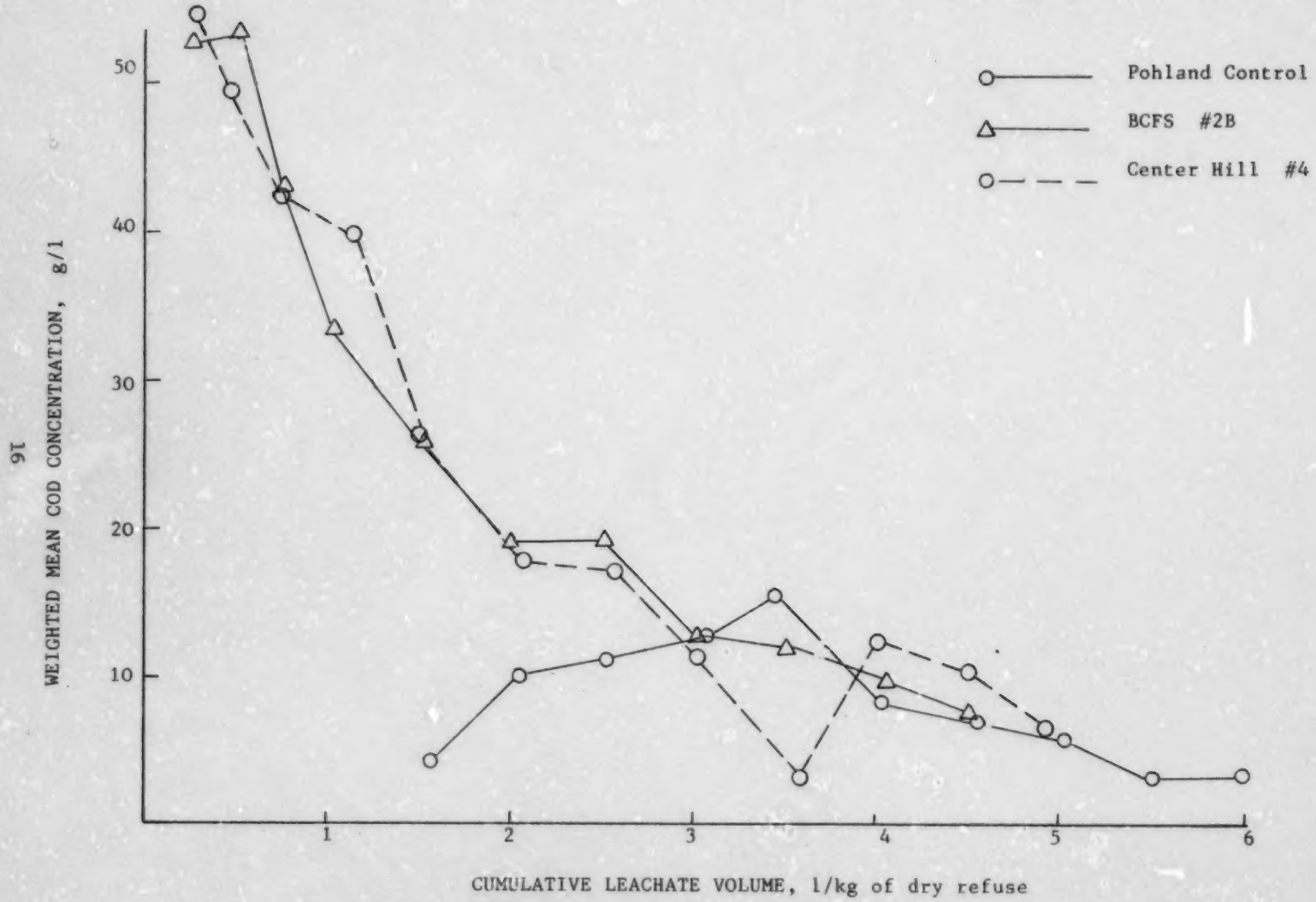

Figure 6. Small cell COD concentration history

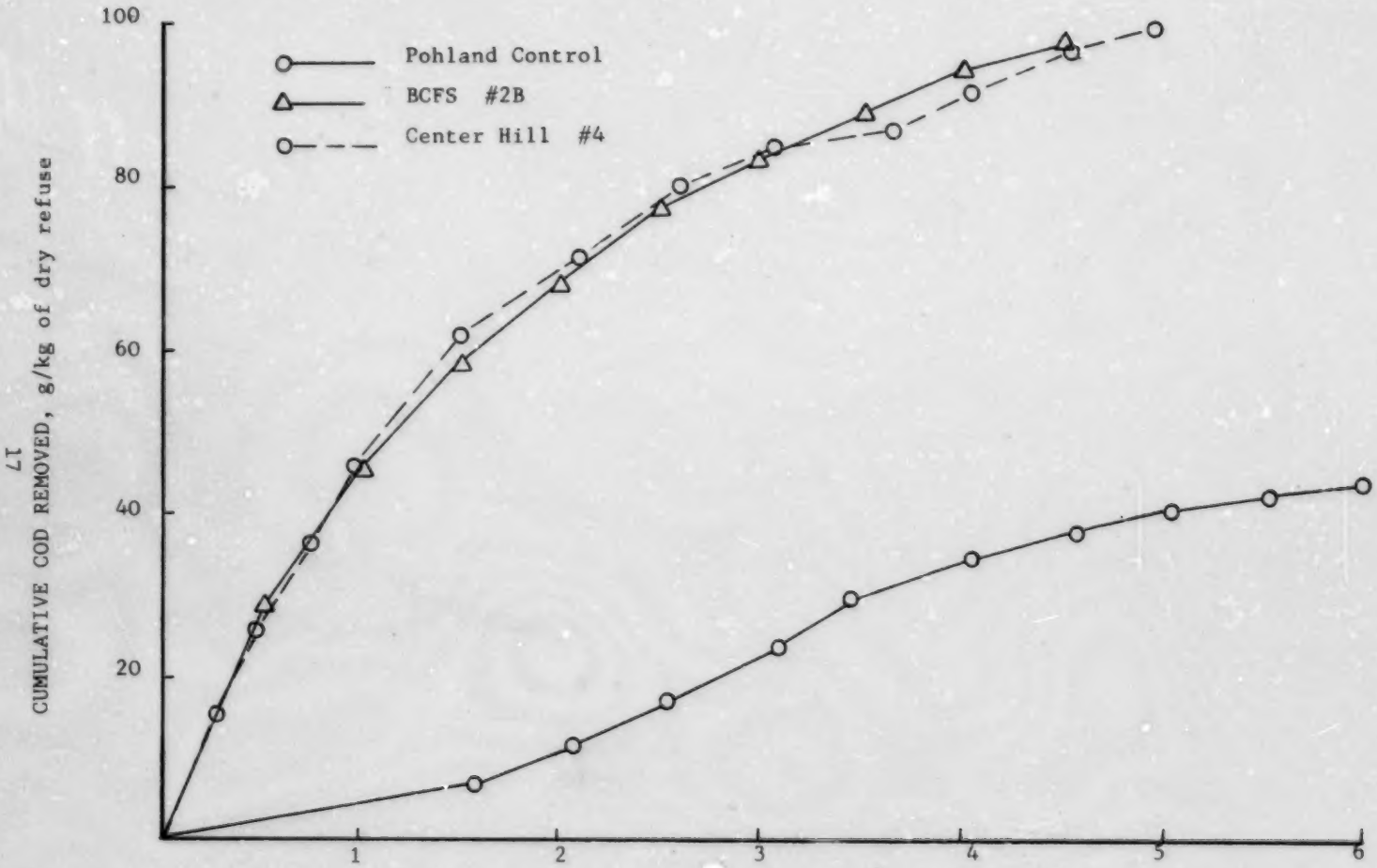

Figure 7. Small cell COD mass removal.

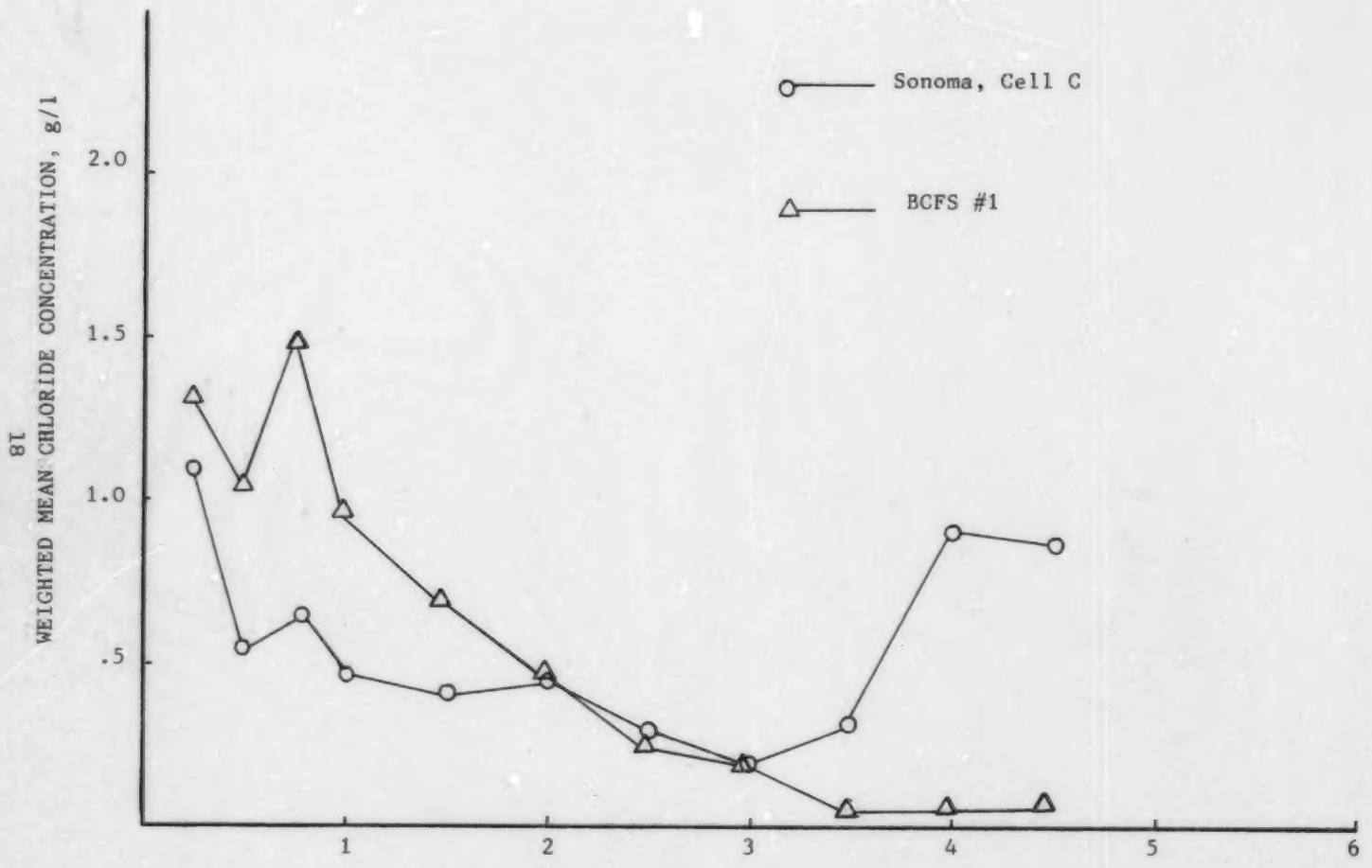

Figure 8. Chloride concentration history.

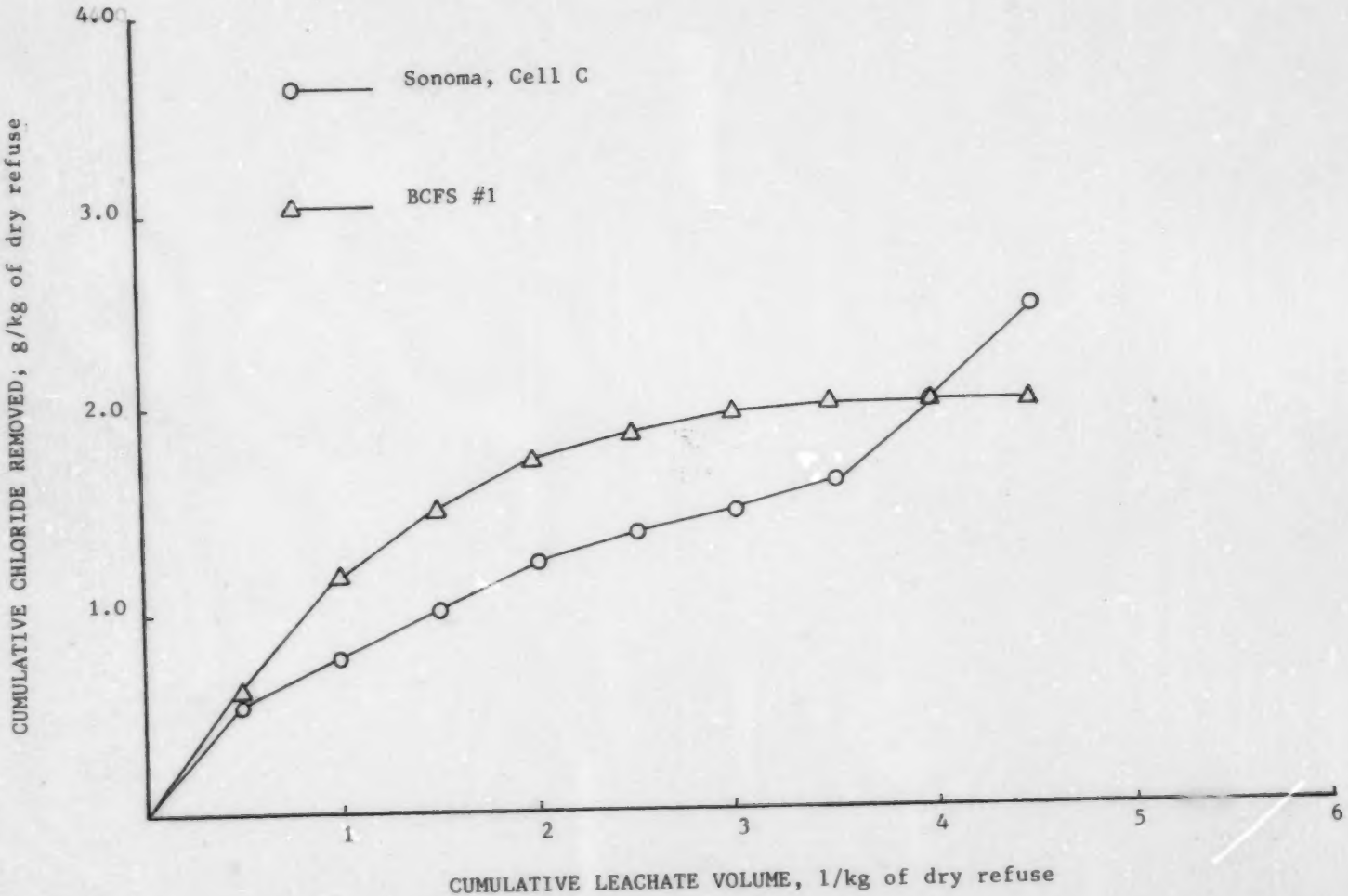

Figure 9. Chloride mass removal

For the small-scale cells chloride weighted mean concentrations for all three of the studies ranged within 10-250 mg/l after 2.0 l/kg of dry refuse of leachate had been collected. While both the BCFS #2B and Center Hill #4 showed the characteristic early peak, the rate of drop in values was quite different in the initial stage of leaching. This contributes to the widely differing mass removal curves in Figure 11. Again the data from the Pohland studies indicated lower concentrations and mass removals. Mass removal from BCFS #2B was quite similar to that from the two field scale cells.

Iron--

Concentration histories for iron leached from the five cells is shown in Figures 12 and 14. Iron was not measured early in the Sonoma study so there was no early peak information available. As reported for other test cells iron did not show a rapid decline for any of these cells except cell #2B and remained quite high through the studies. Little similarity between small or field scale cells is apparent from the graphs. The cumulative mass removal plots, Figures 13 and 15, show mass removals at 4.5 l/kg of leachate to range from 0.7 - 3.0 g/kg. All of the curves indicate continued high release rates might be expected. If the Pohland data is disregarded due to the lack of accurate water volumes, the cumulative mass removed for the other four cells appears to be inversely proportional to the rate of leachate production. The Sonoma County and Center Hill mass removal rates are depressed below those of the Boone County studies, perhaps due to their higher annual leachate production and subsequent dilutions. This would indicate that the iron availability from the waste is more limited than for COD and chloride.
A similar relation of concentration and mass removal of iron to leachate production rate was apparent in the Center Hill data for four small cells receiving varied amounts of precipitation(8).

Sodium--

Leachate concentration data for sodium was available from all but the Center Hill study, where analysis for the parameter was discontinued. The weighted mean concentration history and mass removal for the two field scale cells are plotted in Figures 16 and 17. As with COD and to a lesser extent chloride, early peaks and subsequent concentration ranges exhibit similarity for the two cells even though the leachate flow rate for Sonoma C was over three times higher than for BCFS #1. Cumulative mass removals remained within .2 g/kg of dry refuse over the 4.5 l/kg removal history. Both the concentration and mass data indicate a continuing trend towards lower removal rates. For the two small cells the lack of early data from the Pohland study prior to 1.5 l/kg of dry refuse prevented a meaningful comparison of small cell concentrations and mass removals from Figures 18 and 19. The rate and quantity of mass removed from BCFS #2B is almost identical to that experienced in the Sonoma and BCFS #1 studies.

Potassium--

Potassium concentrations were only available for the two field scale cells and BCFS #2B. Plots of Sonoma and BCFS #1 concentrations and mass removals are shown in Figures 20 and 21. Both cells showed early peak con-

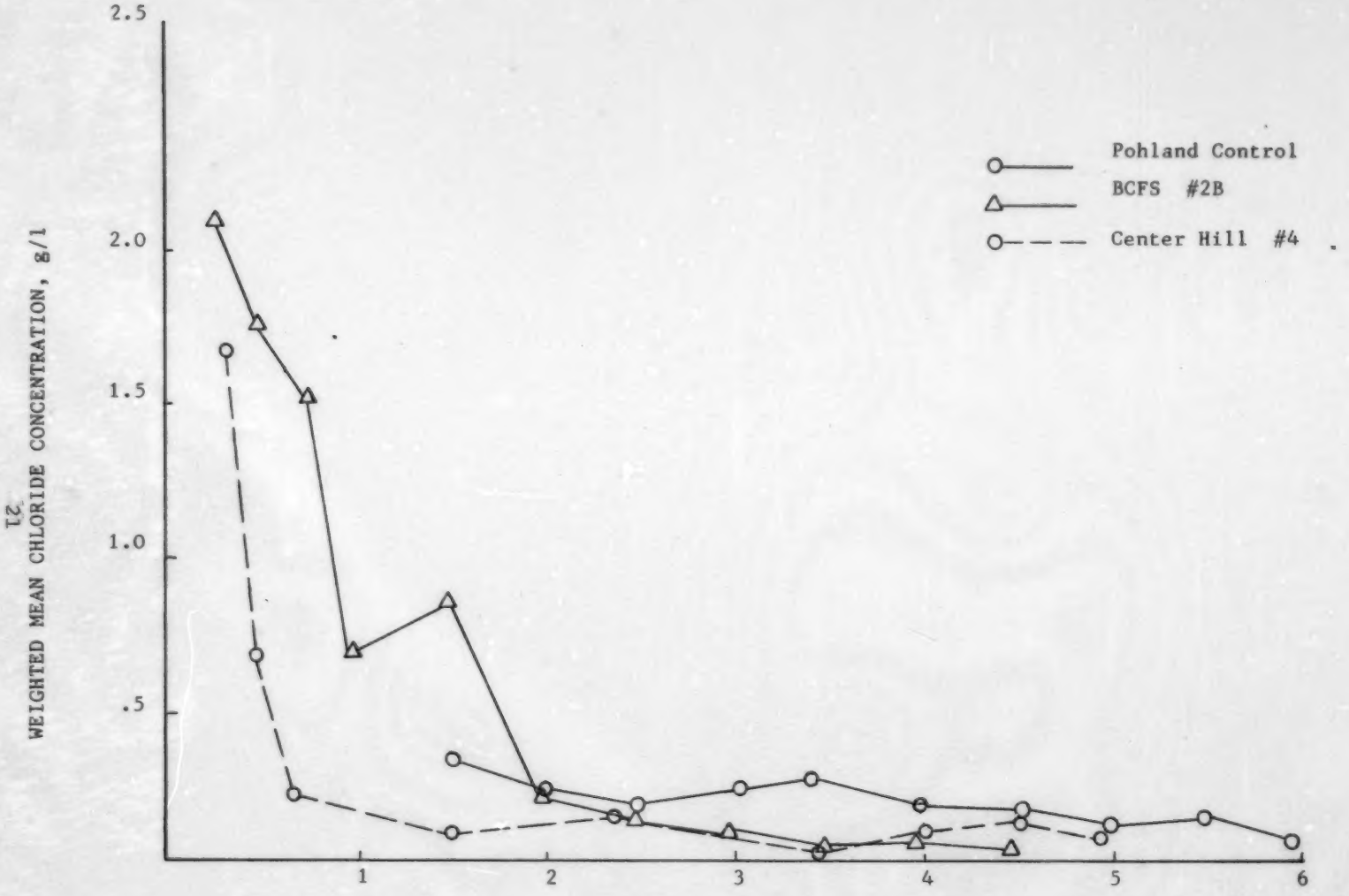

Figure 10. Small cell chloride concentration history

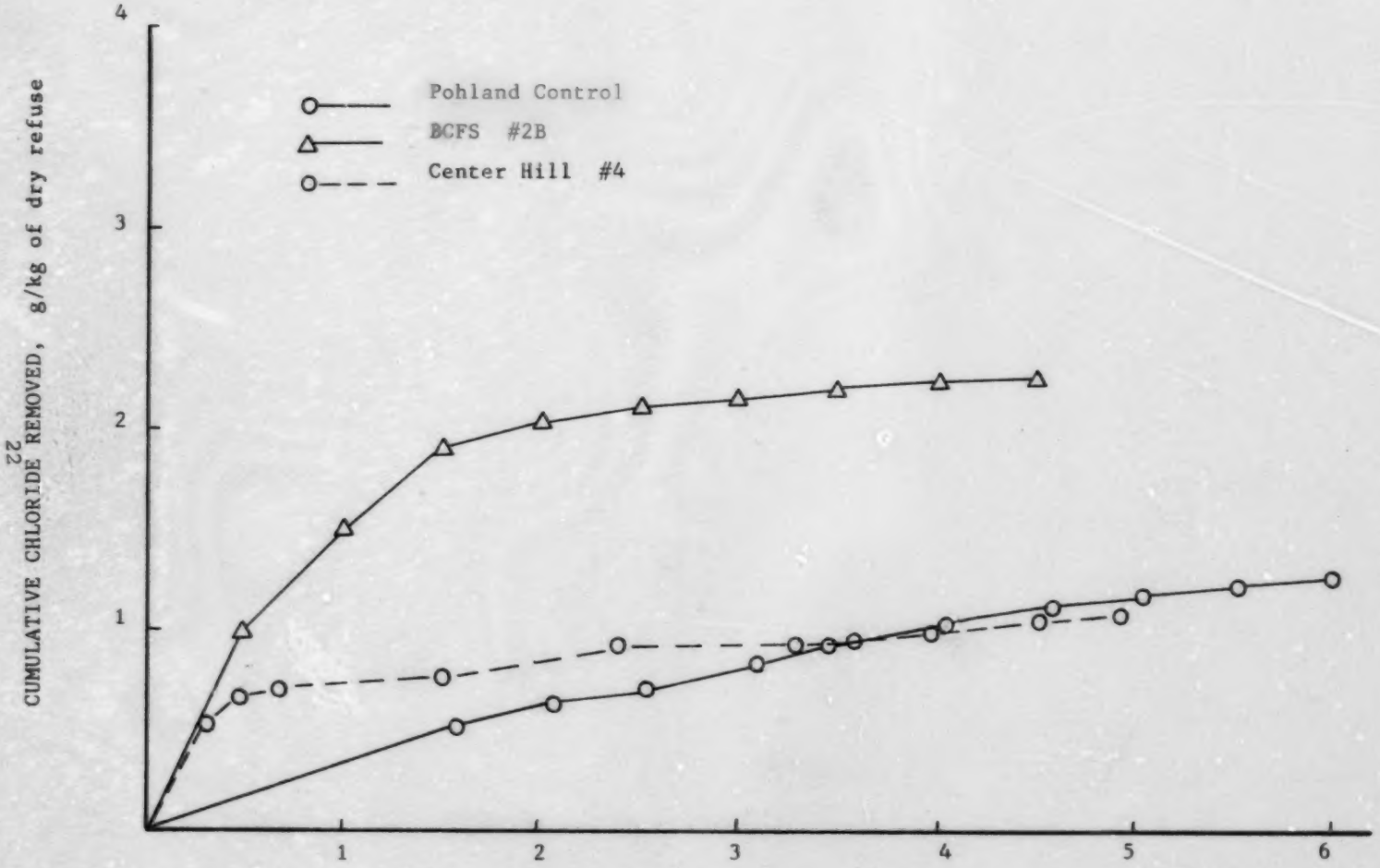

Figure 11. Small cell chloride mass removal.

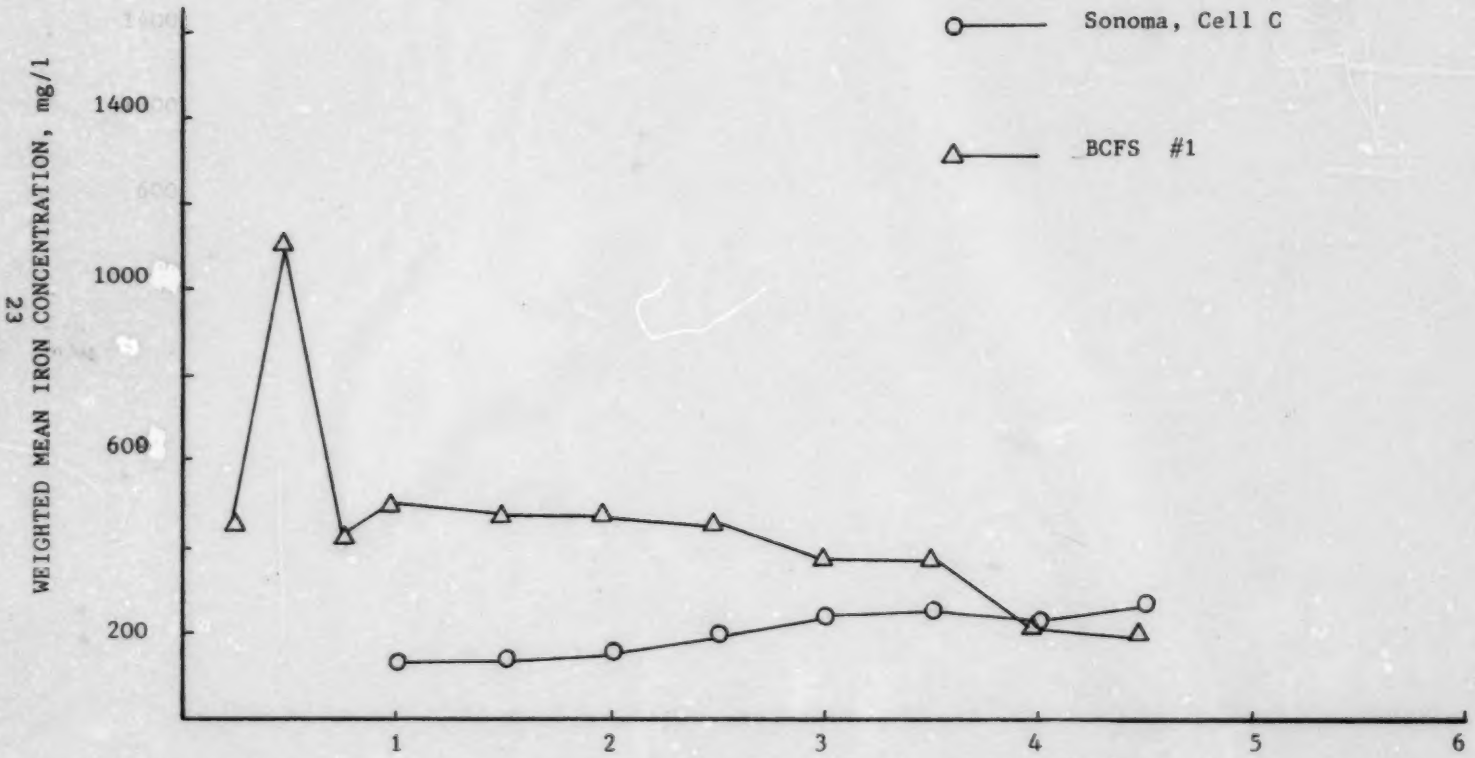

Figure 12. Iron concentration history

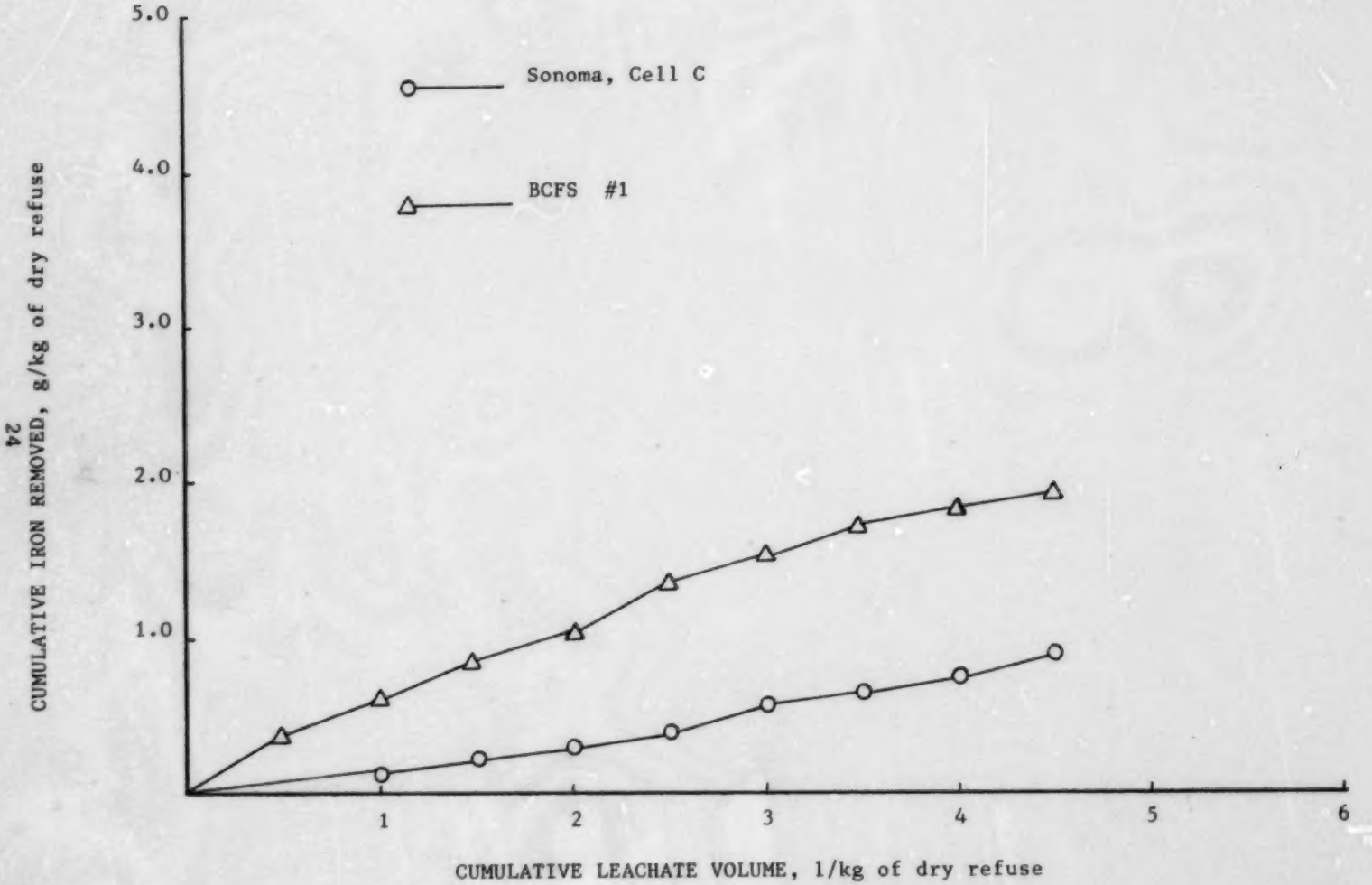

Figure 13. Iron mass removal

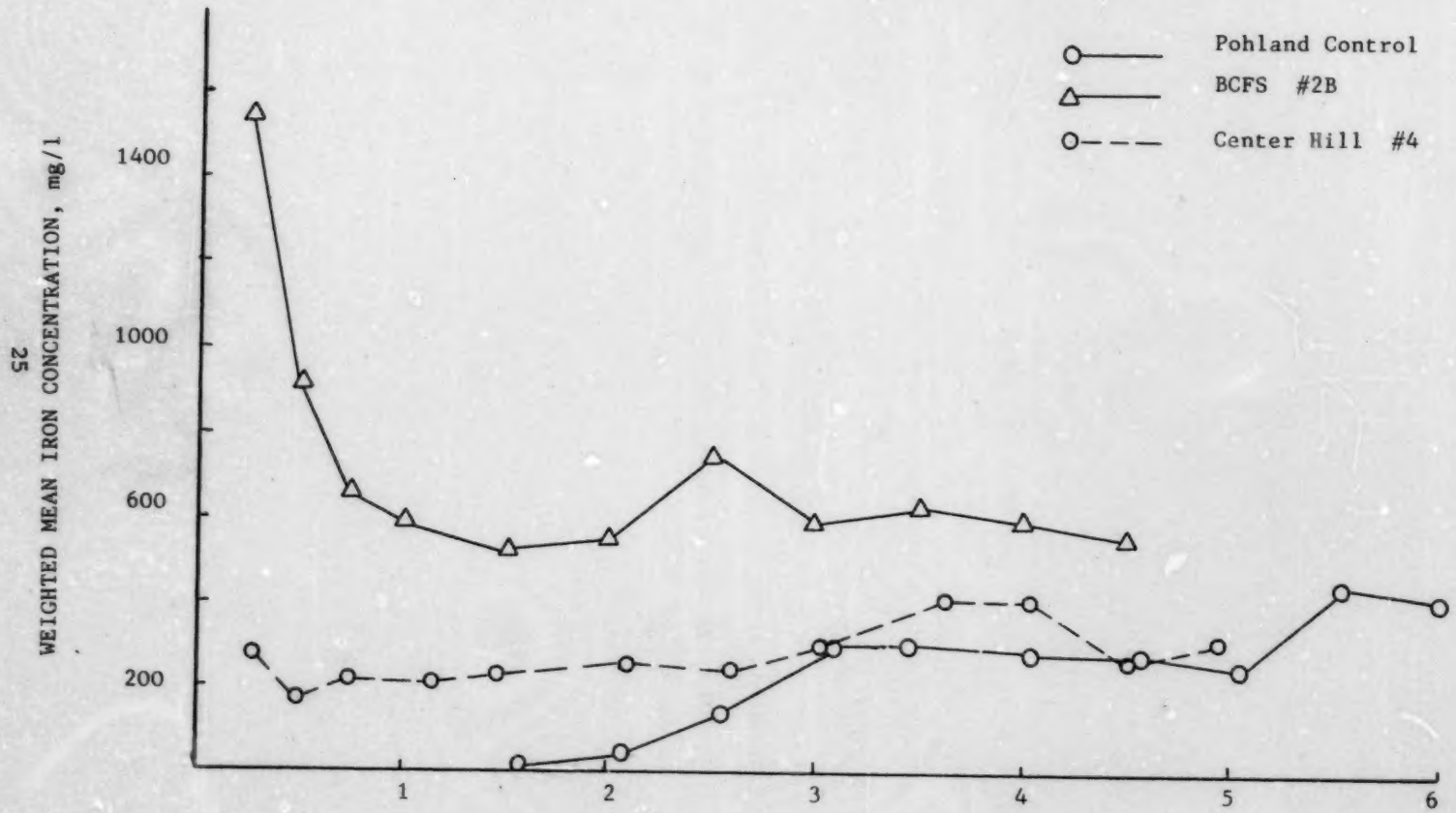

Figure 14. Small cell iron concentration history

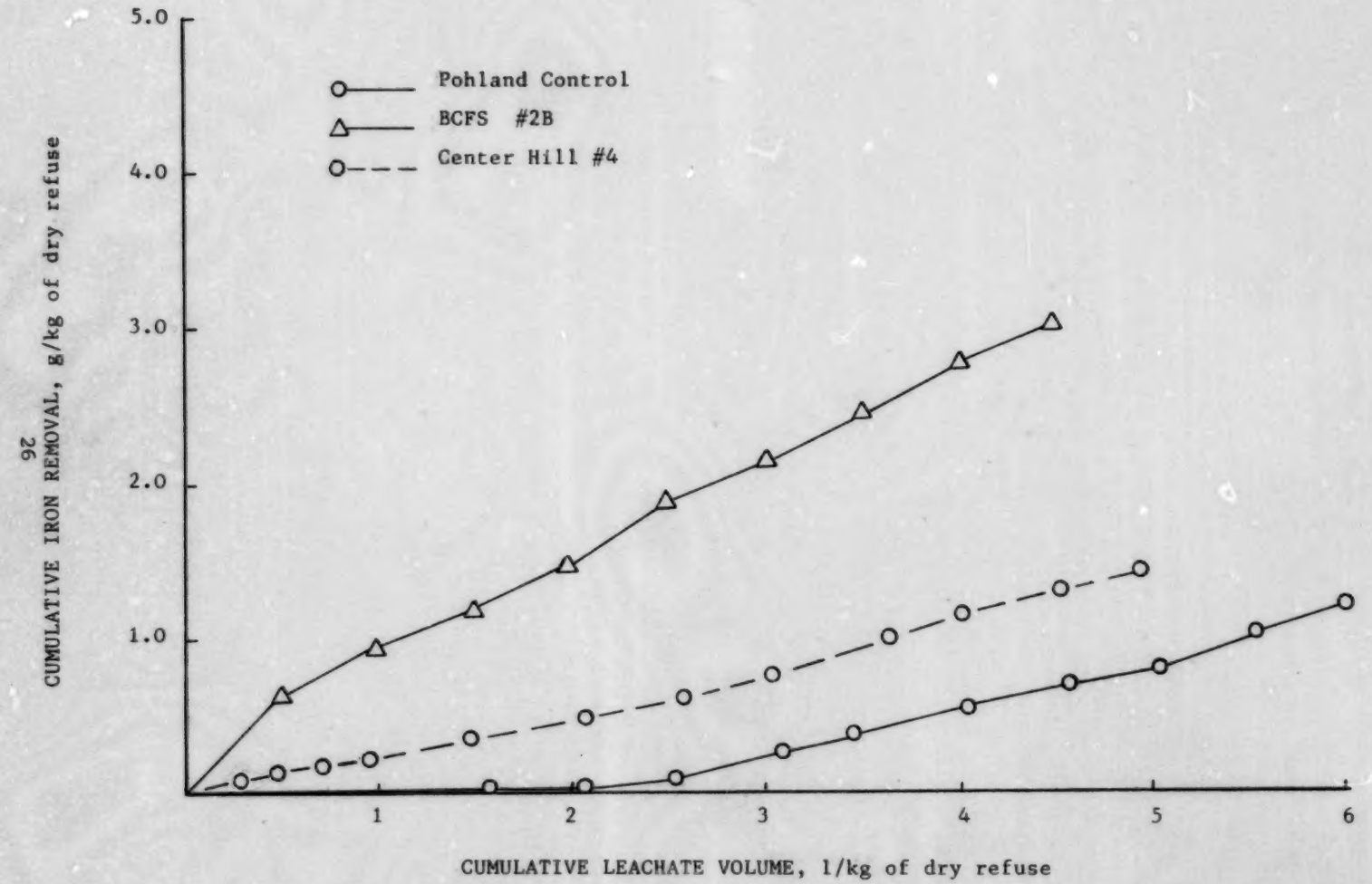

Figure 15. Small cell iron mass removal.

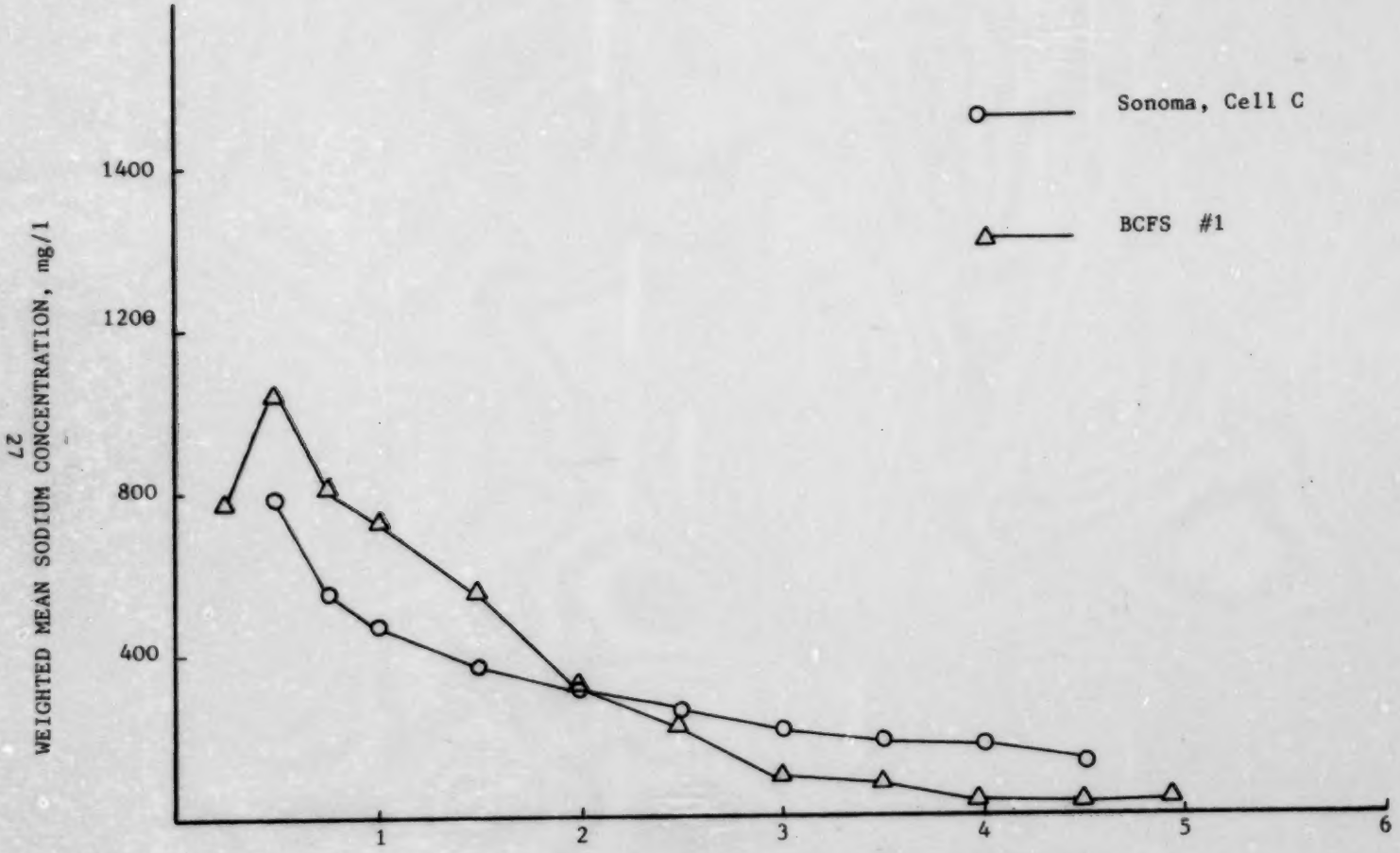

Figure 16. Sodium concentration history

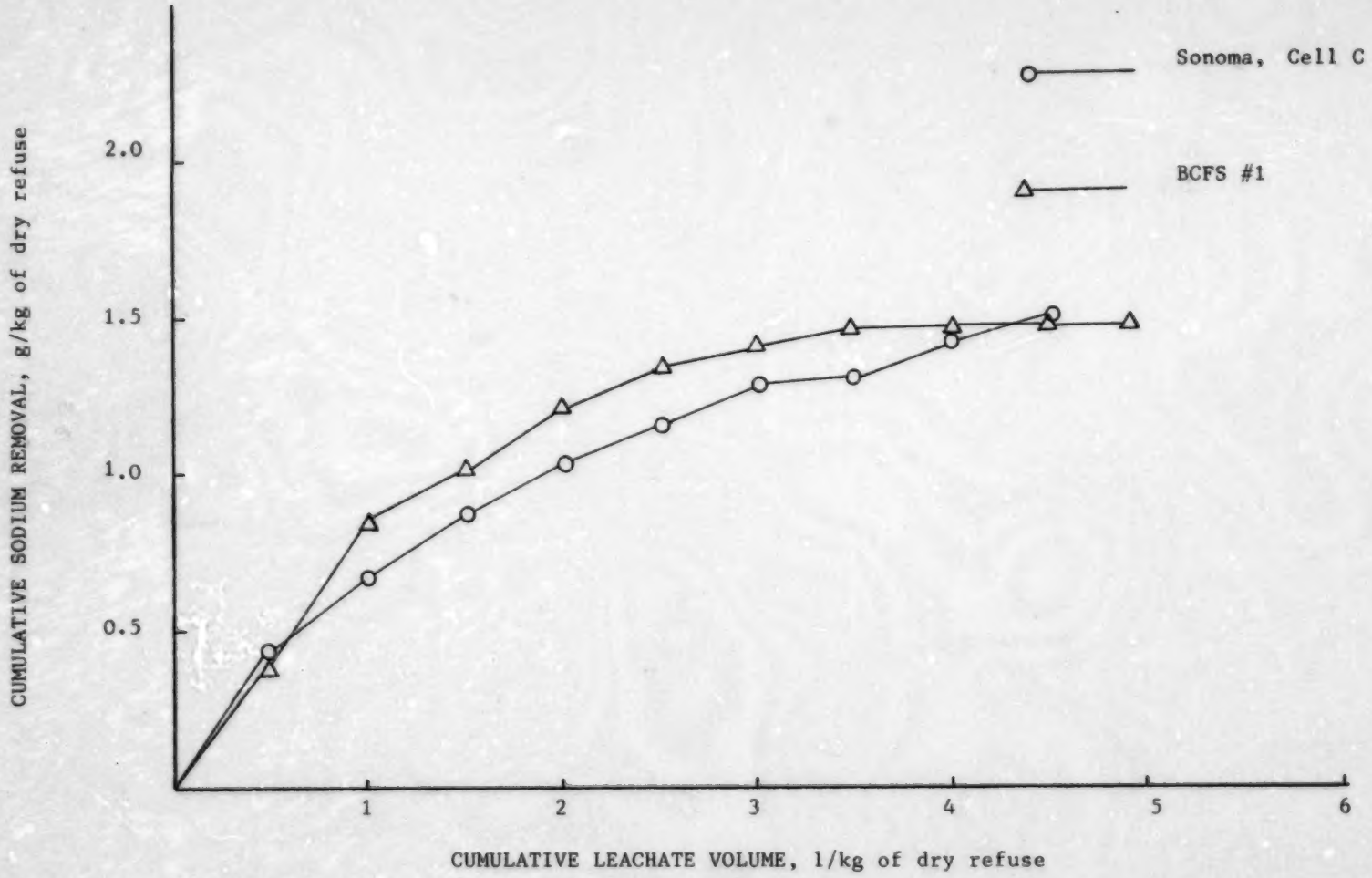

Figure 17. Sodium mass removal

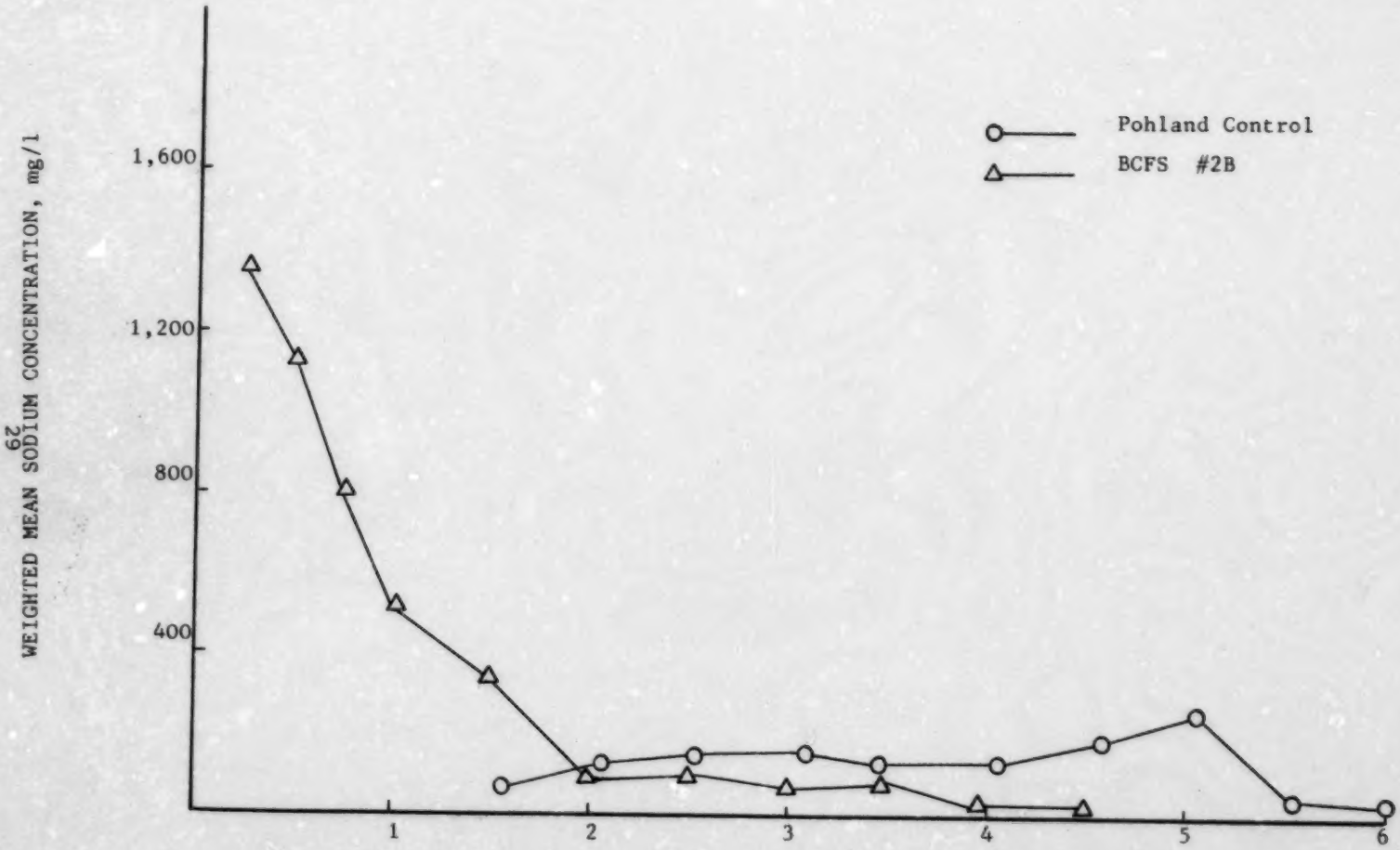

Figure 18. Small cell sodium concentration history

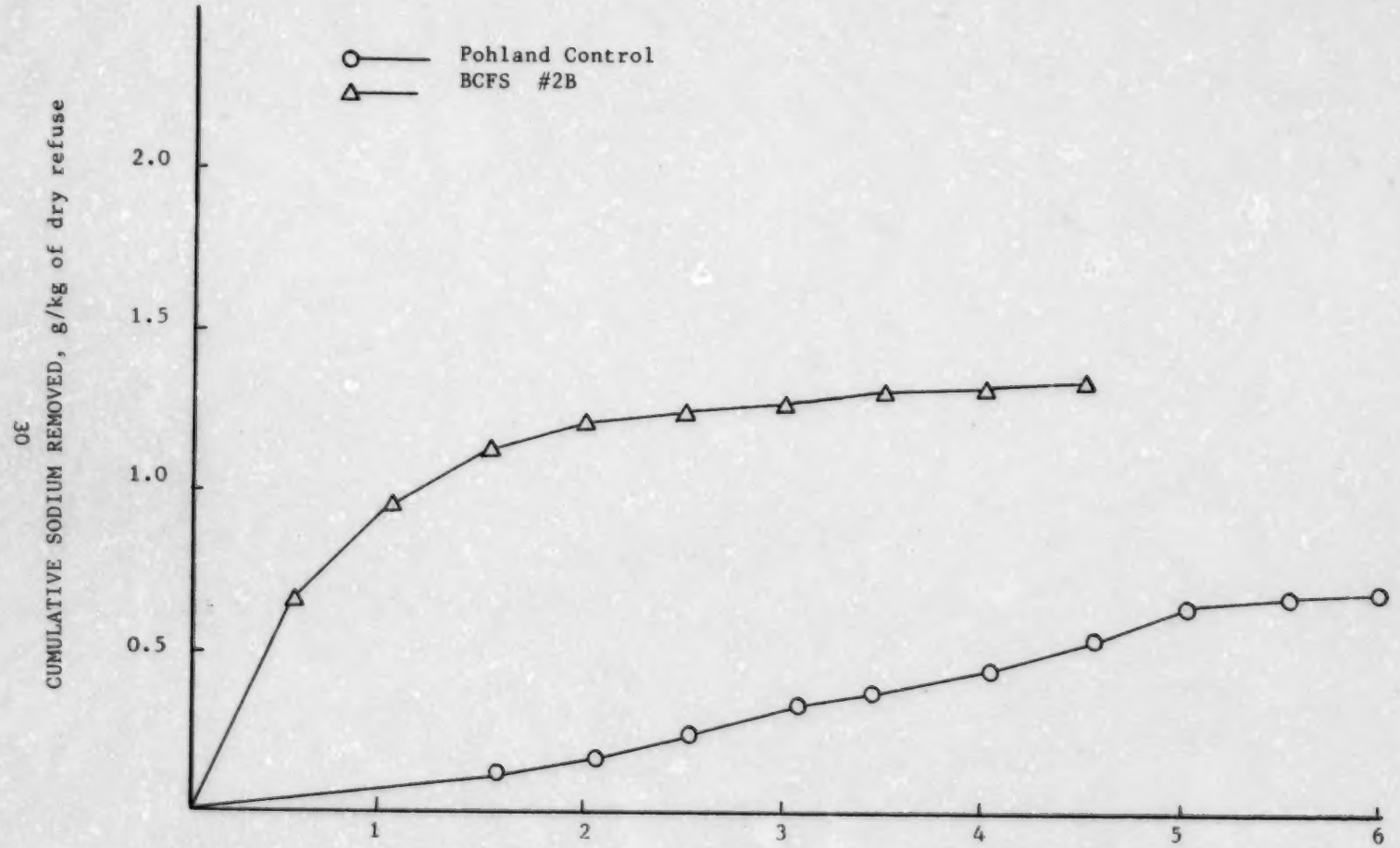

Figure 19. Small cell sodium mass removal

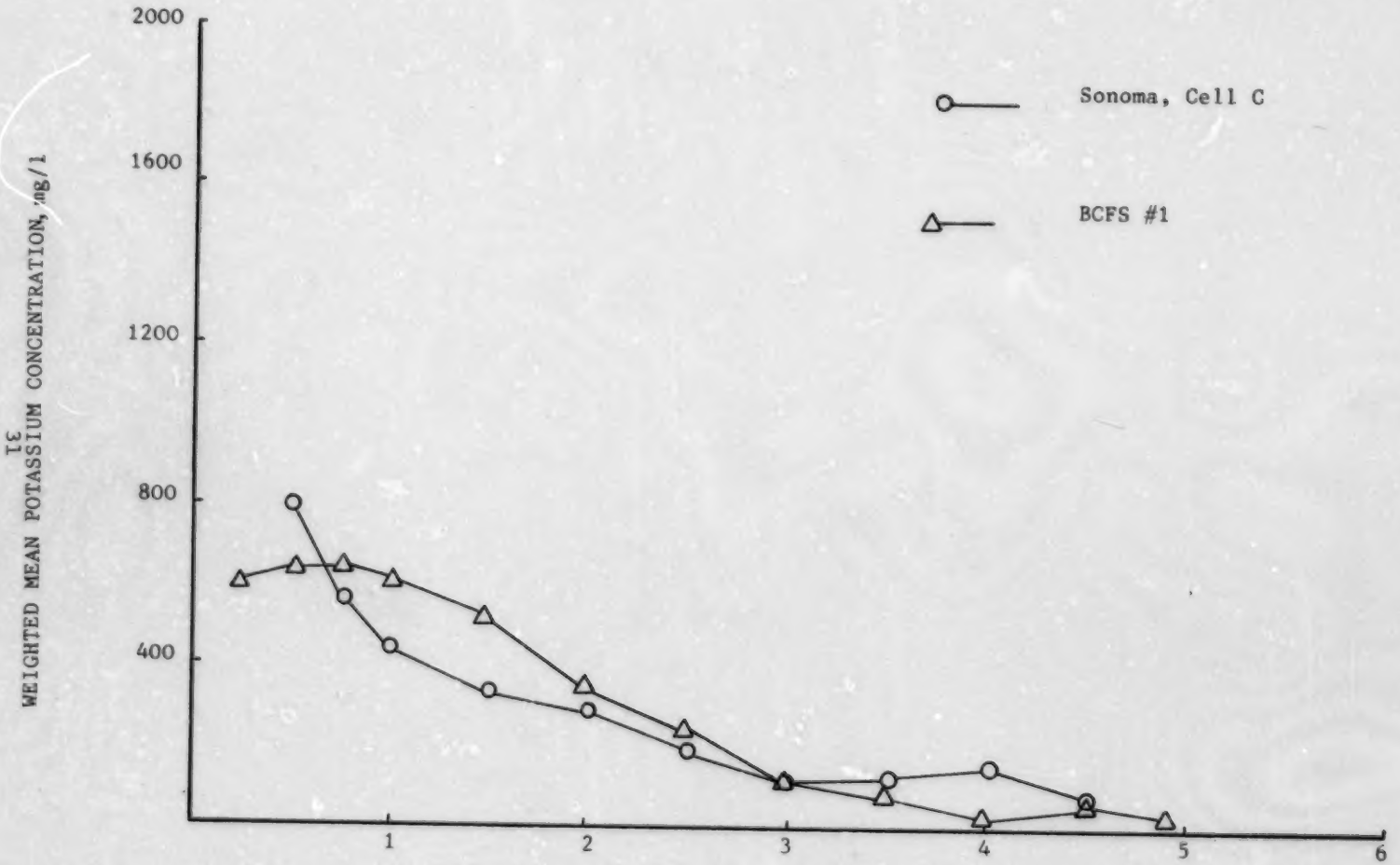

Figure 20. Potassium concentration history

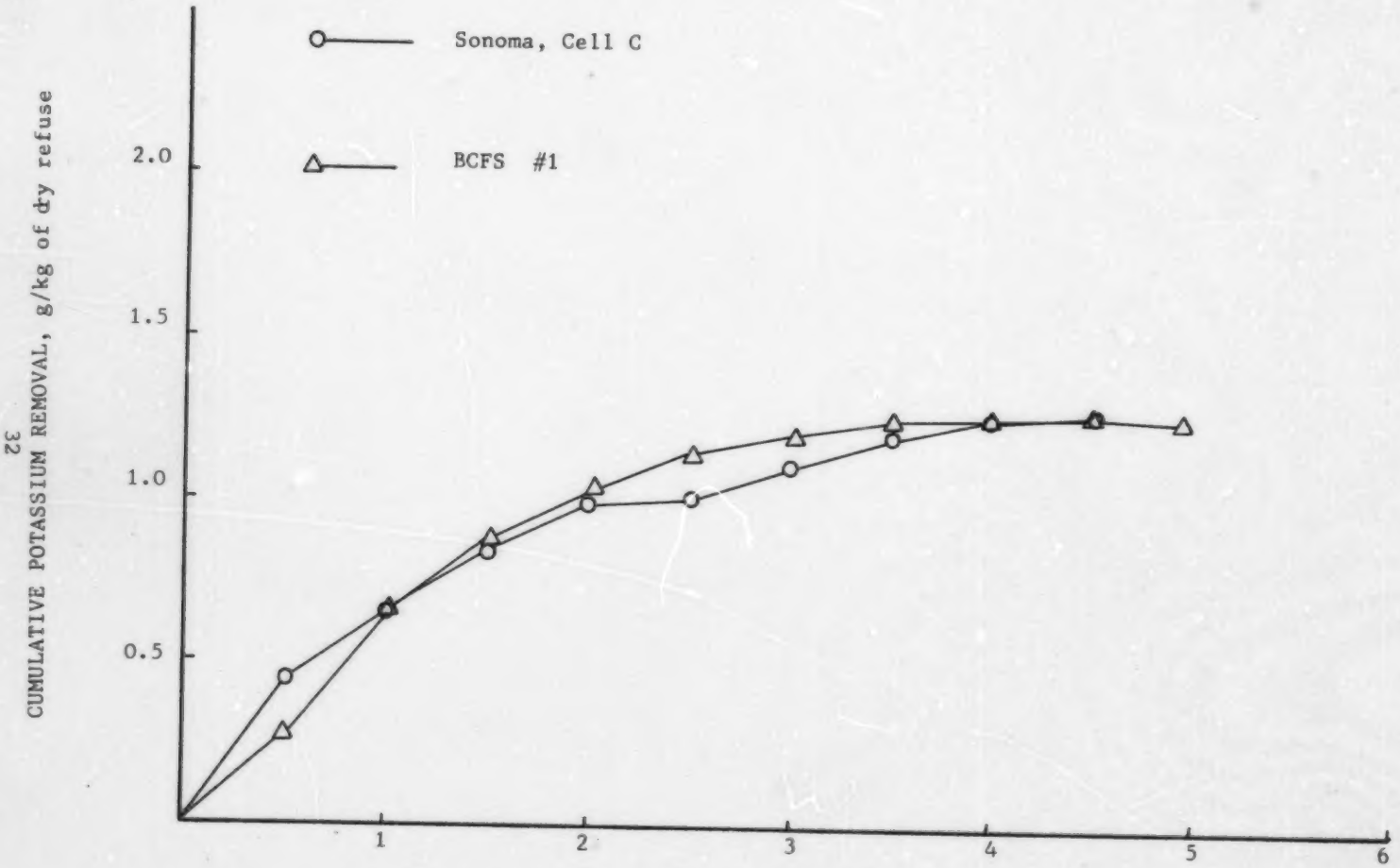

Figure 21. Potassium mass removal

centrations and gradual decreases in weighted mean concentrations. Mass removals for the two field-scale cells were almost identical, but totaled only about 60% of that recorded for the small-scale BCFS #2B at 4.5 l/kg of leachate. No dilution is noted in the concentrations from Sonoma C as compared to BCFS #1.

Calcium--

Weighted mean concentration of calcium in the Sonoma County study was as much as 1,000 mg/l lower than for BCFS #1 over the initial 3.0 l/kg of leachate collected. Thereafter concentrations were more comparable, as shown in Figure 22. These depressed concentrations caused different mass removal curves as shown in Figure 23. Total calcium leached from the Sonoma cell was only 68% of the amount from BCFS #1 at a cumulative leachate volume of 4.5 l/kg of dry refuse. Dilution due to the higher flow rate may have been a factor. Calcium concentrations and mass removals for the Pohland control cell and BCFS #2B are shown in Figures 24 and 25. Again the lack of early data from the Pohland study and the lack of water volumes precludes meaningful comparison.

Ammonia Nitrogen--

Concentration data for ammonia nitrogen was available from all but the Center Hill study. The weighted mean concentration and mass removal data is plotted in Figures 26-29. For the two large cells similar peaks in the 400-600 mg/l range were recorded. Although the later concentrations recorded from Sonoma C were 50-1000 mg/l higher than those for BCFS #1, the mass removal curves differed by less than 15% at a cumulative leachate of 4.5 l/kg of dry refuse. Mass removal from BCFS #2B was 50% higher than that from the field-scale cells due to much higher concentrations early in the study. Data from the Pohland study was not meaningful in the comparison.

Mathematical Model Comparison

Another method for determining similarity of leachate concentration trends from test cells is to compare mathematical modeling equation constants. One such semi-empirical model has been described in Reference 1. This equation describes the concentration history as the exponential function in Equation 1:

$$C = C_o e^{-(\frac{q}{v} + k)t} \quad (1)$$

where C = concentration at any time
C_o = peak concentration at field capacity or t = 0
q = leachate flow rate, l/kg of dry refuse/year
v = total water retained in the refuse at field capacity, l/kg of dry refuse
k = rate constant
t = cumulative time since field capacity was reached, years

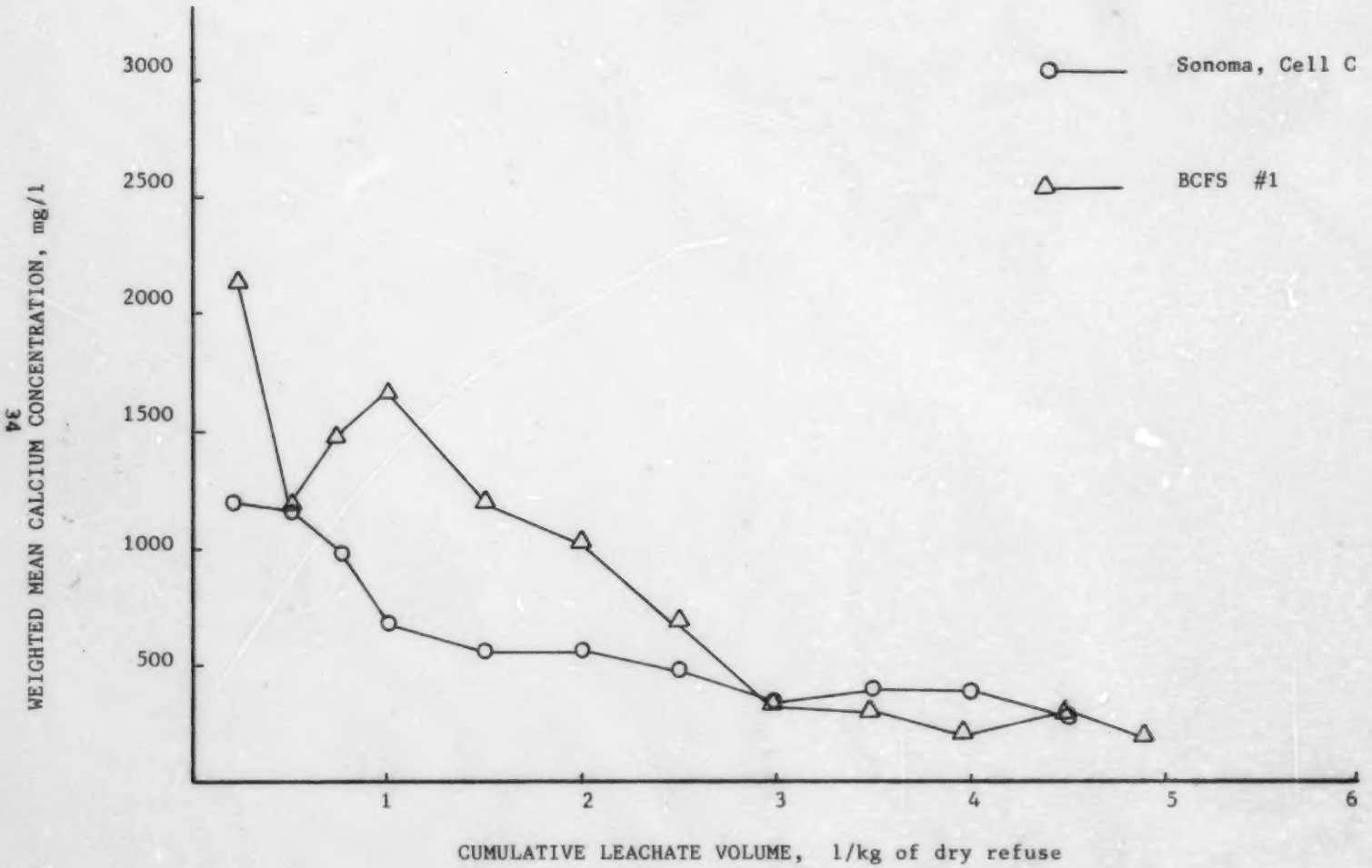

Figure 22. Calcium concentration history

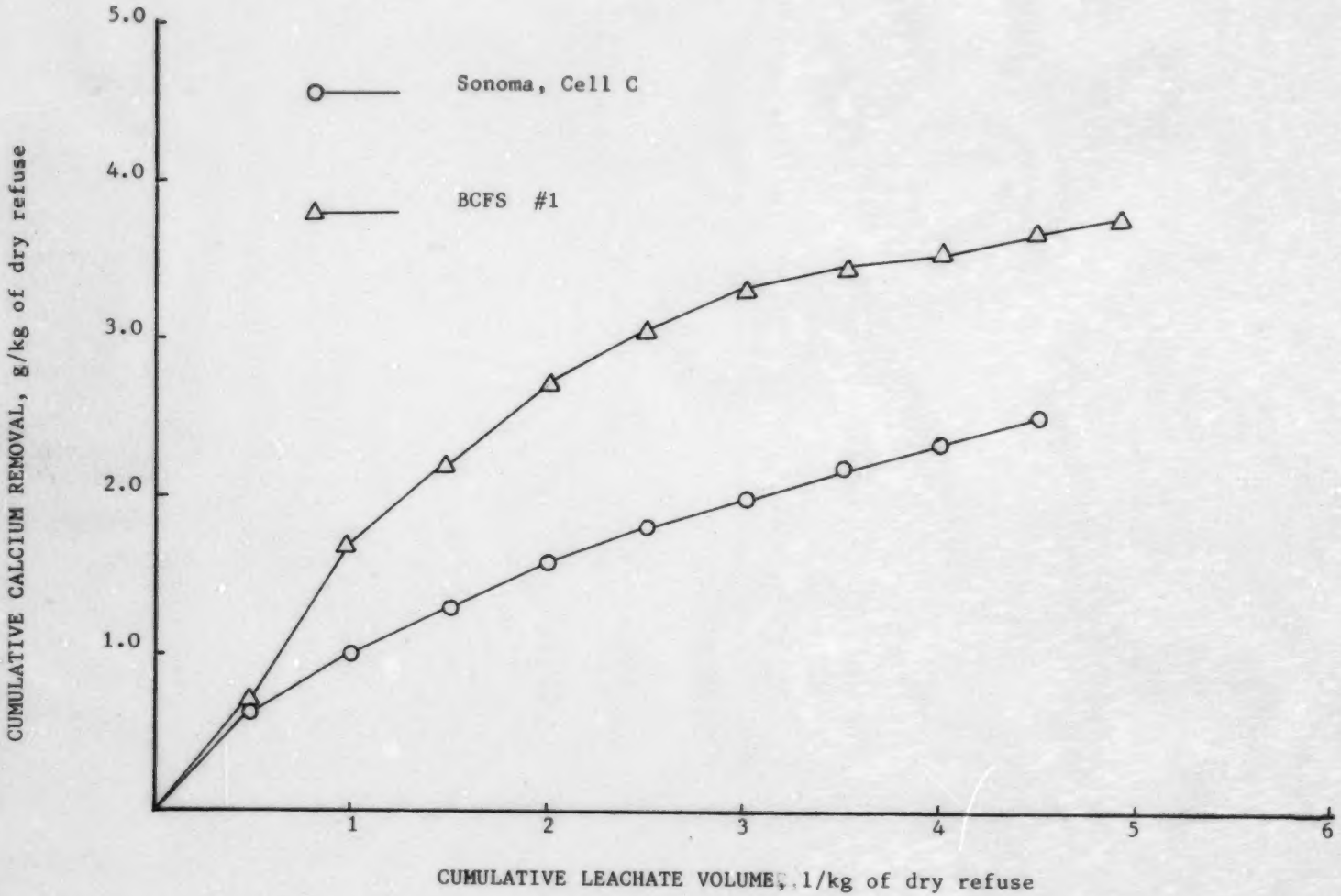

Figure 23. Calcium mass removal

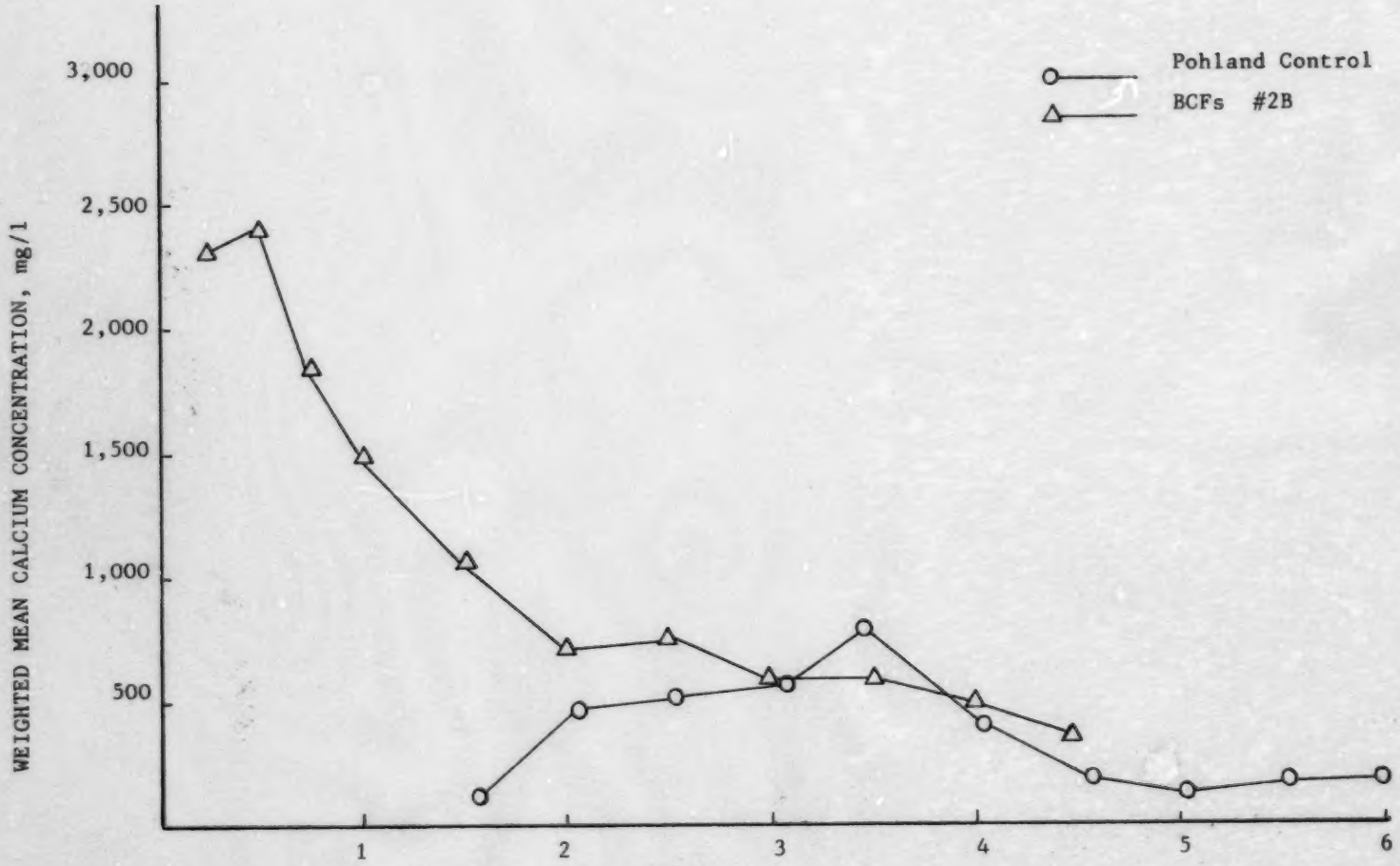

Figure 24. Small cell calcium concentration history

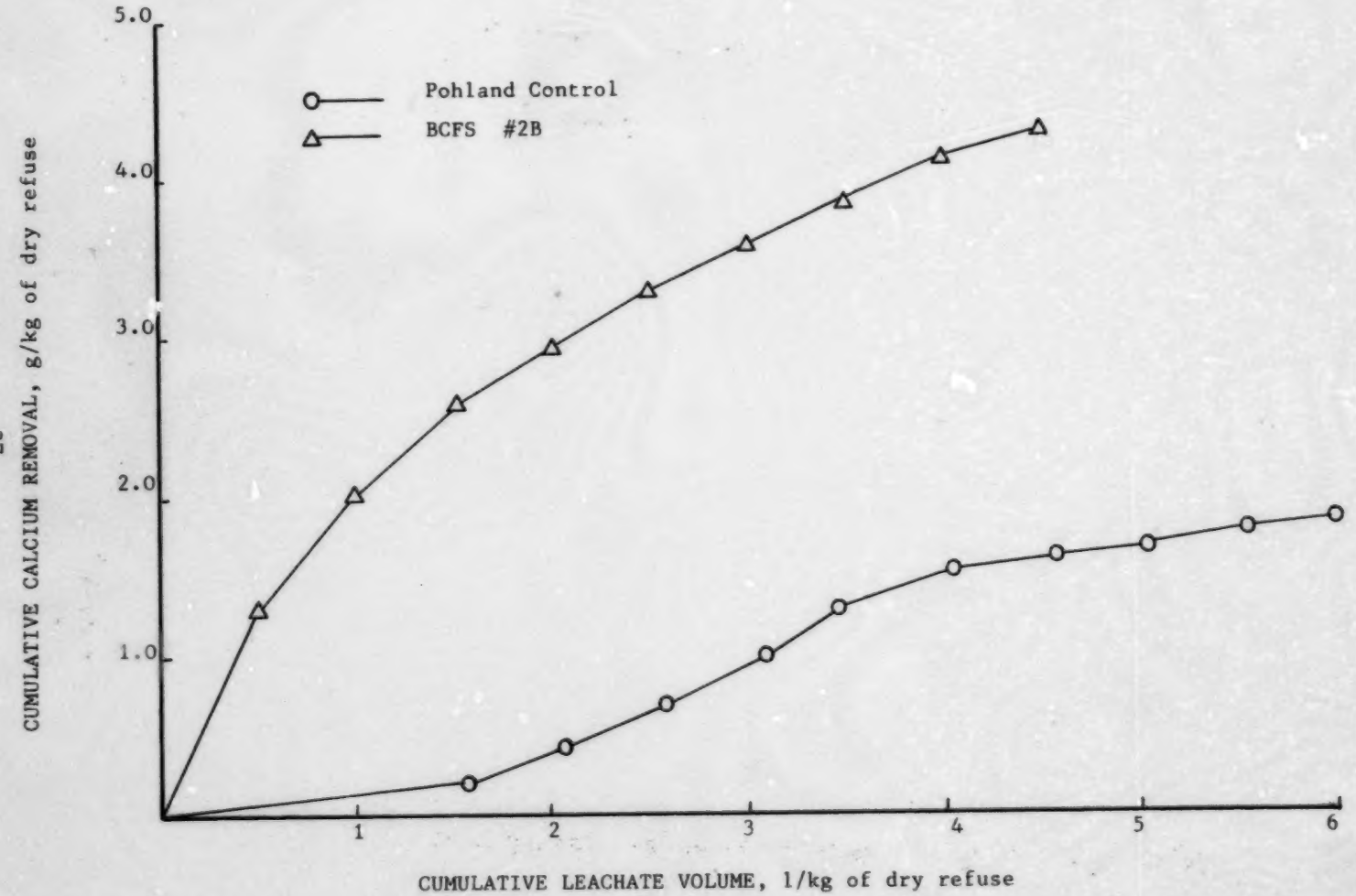

Figure 25. Small cell calcium mass removal

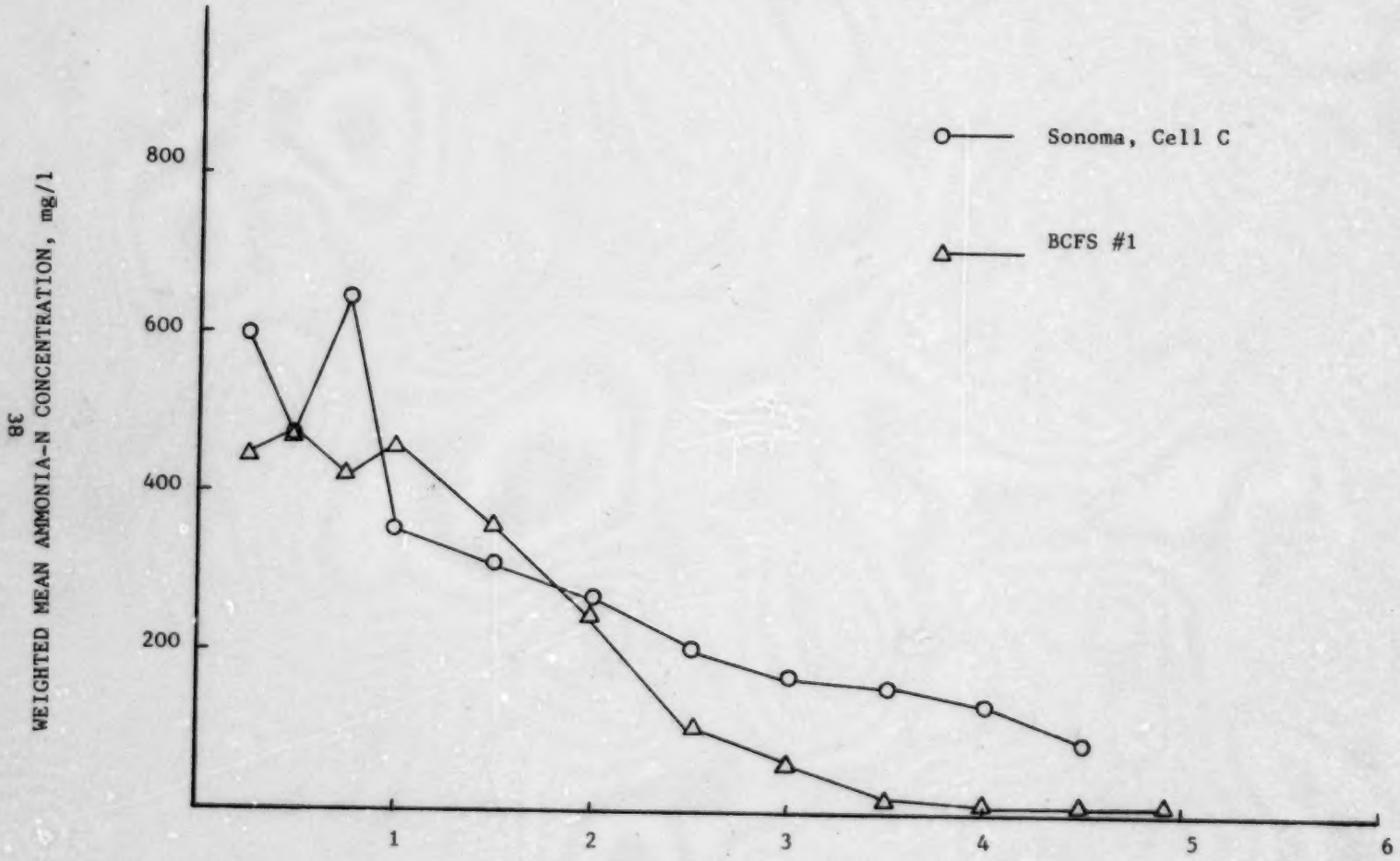

Figure 26. Ammonia-N concentration history

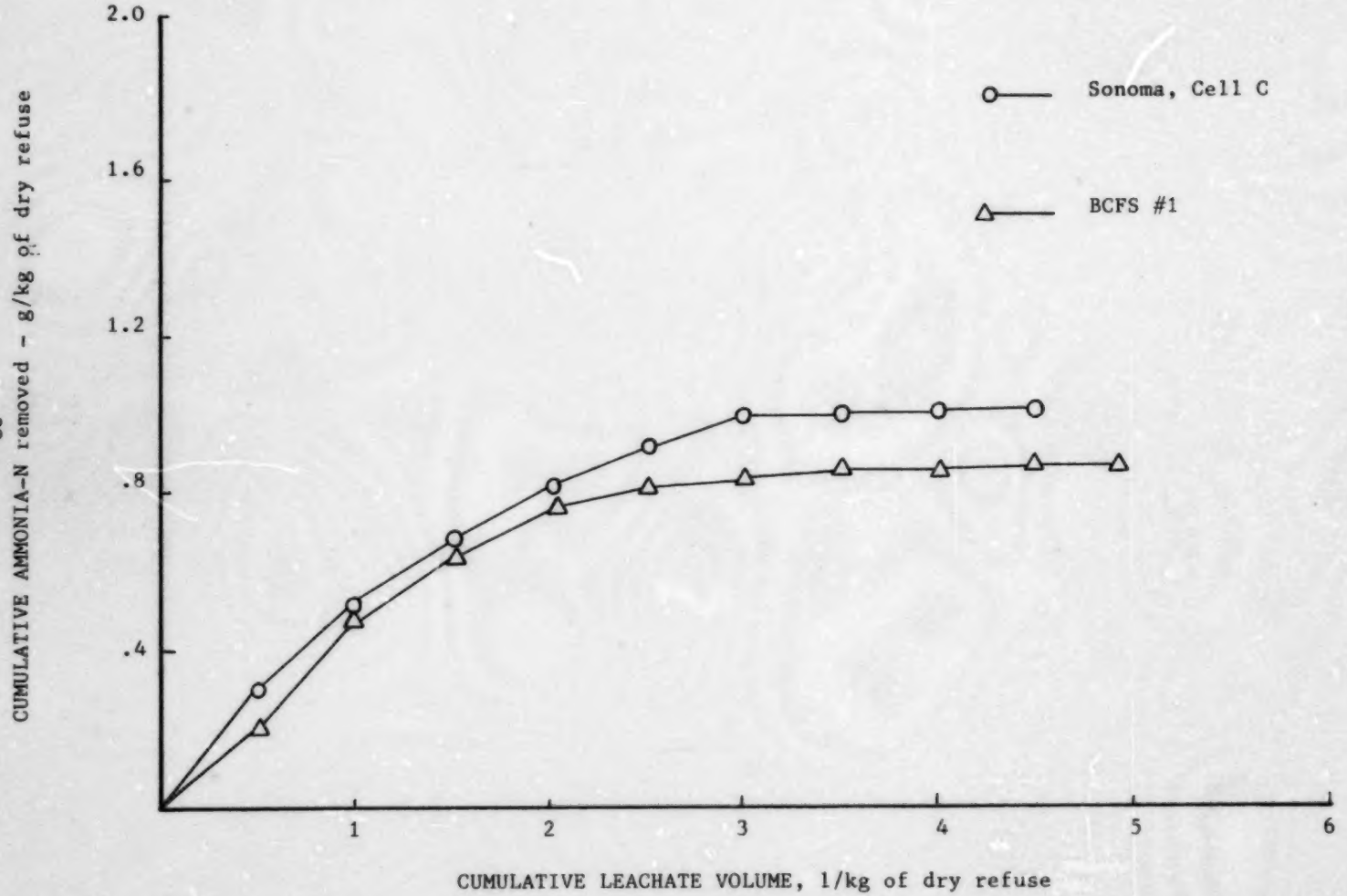

Figure 27. Ammonia-N mass removal

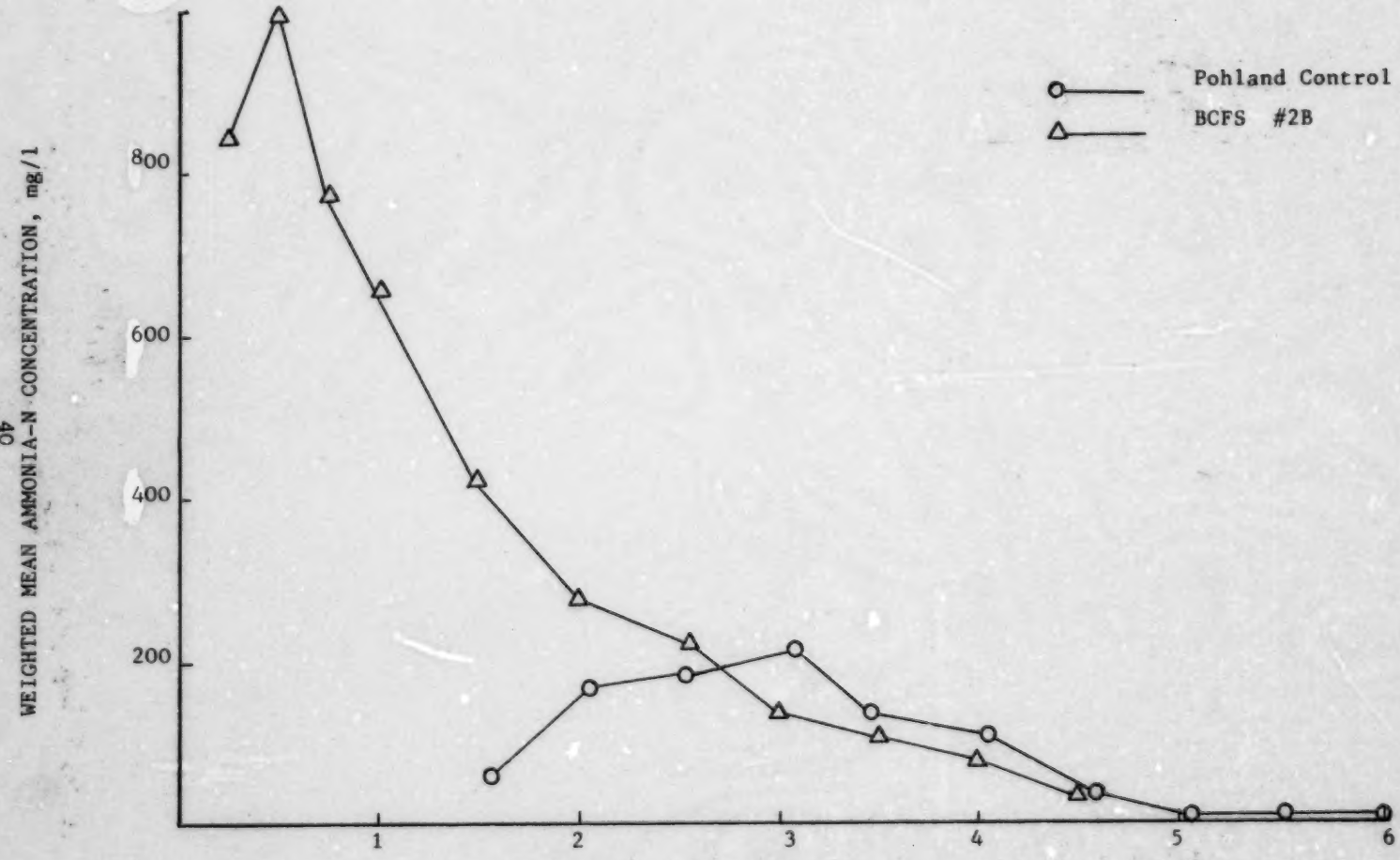

Figure 28. Small cell ammonia-N concentration history

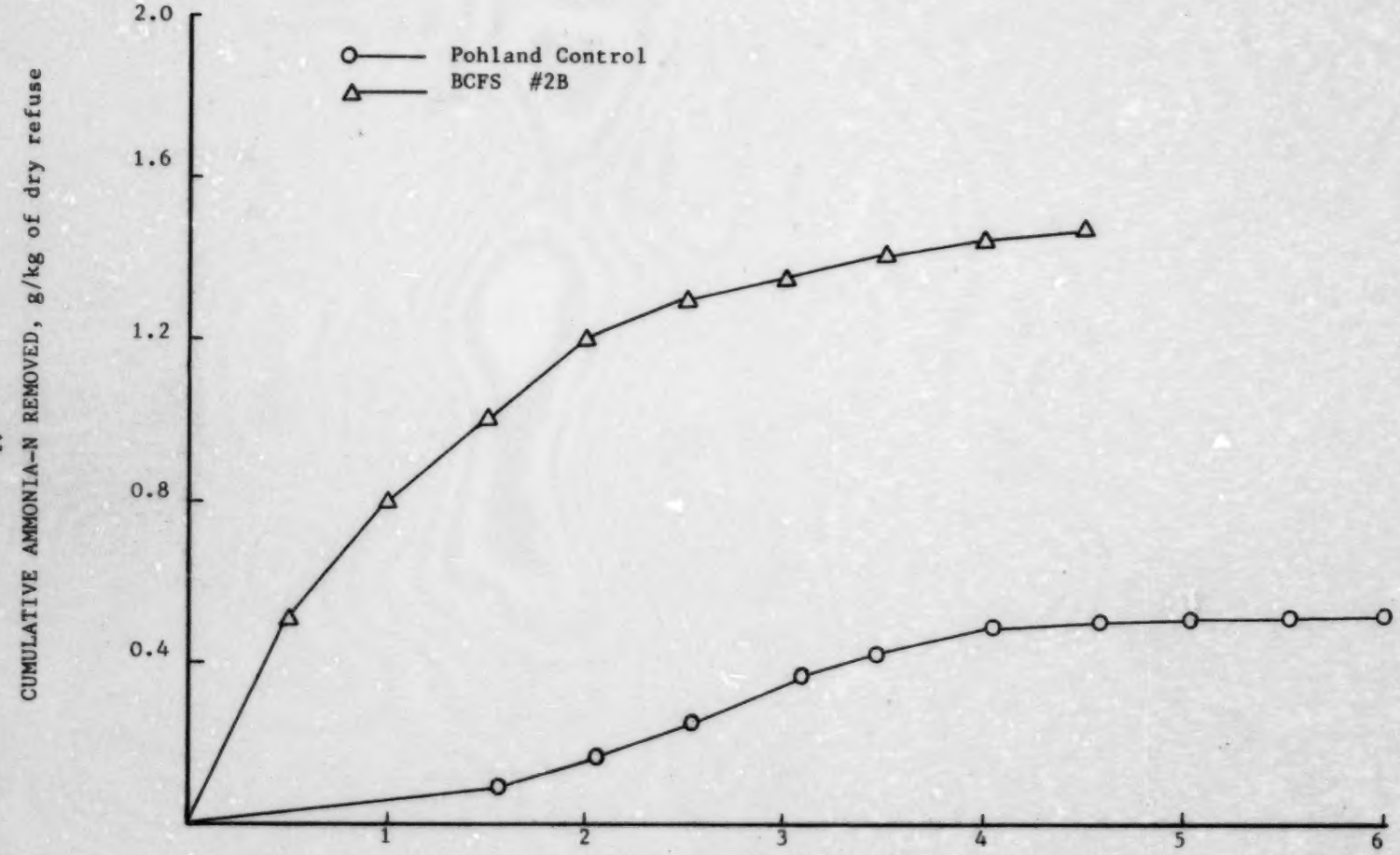

Figure 29. Small cell ammonia-N mass removal

A log transform of this equation reduces it to a form for which a least square regression analysis can be performed. The linear constants from this analysis provide the "best fit" C_o and $(\frac{q}{v} - k)$. The value of q can be calculated by a least squares analysis of the leachate collection history and v can be obtained from leachate volume data. Typically v would be in the 1.0-1.5 l/kg of dry refuse range.

The reports from the Boone County (1) and Center Hill (8) projects provided values of q and v for cells BCFS #1 and #2B and Center Hill #4. The field capacity in the Sonoma County study was estimated to be equivalent to 1.20 l/kg based on cumulative water storage within the cell. The leachate flow rate at Sonoma County after field capacity of the refuse was reached was approximately 1.82 l/kg of dry refuse/year. Summarized data for q and v for the four test cells is shown in Table 3. Adequate leachate volume data from the Pohland study was not available.

TABLE 3. TEST CELL CONSTANTS

Cell	q[a]	v[b]	q/v
BCFS #1	.57	1.22	.47
Sonoma C	1.82	1.20	1.52
BCFS #2B	.58	1.13	.52
Center Hill #4	1.17	1.51	.77

a. l/kg of dry refuse/year
b. l/kg of dry refuse

From the test cell data listed in Table 3, the k coefficient values from the least squares analysis of the log transform equation can be calculated. Values of C_o, k and the correlation coefficient r for the least squares equation are presented in Table 4. Correlation of the simple exponential equation with the leachate history data from field capacity to 4.5-5.0 l/kg of leachate was very good, as evidenced by 13 of the 20 curve fittings having coefficients of .95 or greater. Correlations for iron were typically low. Description of the chloride curve for Sonoma was also poor, due to the questionable high value recorded near the end of the study.

Comparing the concentrations at field capacity (C_o) as projected by the model, generally lower values were obtained for the Sonoma data than for BCFS #1. This was also the case for 2 of the 3 parameters from BCFS #2B and Center Hill #4. In both of these cases, leachate production for Sonoma and Center Hill were higher than the corresponding BCFS studies. This indicates that the higher flow rates (q or q/v) tend to dilute or depress peak concentrations at field capacity.

Also apparent from Table 4 are the differences in the rate constants (k) between the studies. All of the constants for the Sonoma study are much higher than for the corresponding BCFS parameter. Except for COD, the same trend is noticed in comparing BCFS #2B to Center Hill #4. For the special case of C_o being the same for two test cells, the ratio of the rate

TABLE 4. EQUATION CONSTANTS

Parameter	BCFS #1			Sonoma C			BCFS #2B			Center Hill #4		
	C_o[a]	k	r[b]	C_o	k	r	C_o	k	r	C_o	k	r
COD	41,560	-.09	.95	26,480	.85	.98	55,220	.25	.99	62,570	.19	.85
Chloride	1,370	-.02	.98	594	1.38	.20	2,380	-.08	.97	512	.30	.65
Iron	635	.33	.80	118	1.93	.96	890	.44	.60	207	.89	.64
Sodium	1,080	-.03	.98	646	.75	.98	-	-	-	-	-	-
Potassium	841	.01	.98	660	.51	.97	-	-	-	-	-	-
Calcium	1,770	.15	.97	1,003	.91	.94	-	-	-	-	-	-
Ammonia N	655	-.14	.98	552	.69	.98	-	-	-	-	-	-

a. mg/l

b. Correlation coefficient

constants (k) for similarly performing cells would be the same as the ratio of the leachate flow rates (q/v). For Sonoma Co. and BCFS #1, this would result in the rate constants for the Sonoma cell being 3.23 times higher than for BCFS #1. None of the values in Table 4 are in this range, possibly due to the differences in the estimated initial concentration, C_o.

With differing values of C_o, one method of comparing cell performance using equation constants is to calculate the total mass of a parameter that would be predicted to be removed from the cell. Integrating the concentration times the flow rate in Equation 1 over infinite time (Cqdt) gives a general expression for total leachable mass.

$$M = \frac{qC_o}{\frac{q}{v} - k} \qquad (2)$$

Using the values of the constants from Table 4, the total leachable masses listed in Table 5 have been calculated.

TABLE 5. ESTIMATED LEACHABLE MASS[a]

Parameter	BCFS #1	Sonoma Cell C
COD	42.3	72.0
Sodium	1.23	1.54
Potassium	1.04	1.19
Calcium	3.15	2.98
Ammonia N	.61	1.21

a. All values in g/kg of dry refuse

These results indicate reasonable similarity for 3 of the 5 parameters checked. For COD over 1.7 times as much mass is projected to be removed from the Sonoma County cell as the BCFS cell #1. This difference can be noted in the COD mass removal curve trends in Figure 5. Equation coefficients for iron could not be used since the concentration history curve (Figure 12) for the Sonoma County cell continues to increase over the data range. This would result in a projection of infinite mass. Chloride mass removal estimates were not made due to the low correlation for the Sonoma County cell.

Graphical comparison of leachate concentration and mass removal trends indicated similar performance over the available data range for the two field scale cells for COD, sodium, potassium and ammonia nitrogen. Comparisons using least squares equation coefficients indicated similarity for sodium, potassium and calcium. The accuracy of the equation comparisons is questionable since the coefficients and total leachable mass projections are derived from an incomplete leaching history of the test cell. While the C_o value would probably not change much with additional long term data, the value of k might vary considerably. Since longer term data is generally not available, it might be beneficial in further performance comparison work to

develop an equation which is dependent on refuse decomposition, mass solubility and leachate flow rates rather than simply assuming as with Equation 1 that mass generation is proportional to the mass in solution in the cell.

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